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(6)

A DISCUSSION OF FACTORS INFLUENCING DISPERSION OF POLLUTANTS IN THE BEAUFORT SEA

by L.F. Giovando and R.H. Herlinveaux

INSTITUTE OF OCEAN SCIENCES
Sidney, B.C.

For additional copies or further information, please write to:

Department of Fisheries and Oceans
Institute of Ocean Sciences
P.O. Box 6000
Sidney, B.C. CANADA
V8L 4B2

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ABSTRACT

A brief history is given of the geographic, hydrographic and oceanographic investigations that were carried out in the Beaufort Sea area during the past 150 years and culminated in the Beaufort Sea Project of 1974-75. The information obtained is utilized to prepare a description of the general physical environment of the area, emphasis being placed on the physical oceanography. This description provides the basis for the consideration of four environmental siutations (scenarios), each of which could strongly influence in its own way, the general destiny of crude oil or other pollutants discharged into the Beaufort Sea. The advantages and disadvantages of the cold-region use of some oil-spill countermeasure techniques presently available are discussed. A summary of the expected general behaviour of pollutants entering the Beaufort Sea is given, together with some suggestions for further studies necessary to refine our insight into this behaviour.

1. INTRODUCTION

The possibility of the presence of significant quantities of oil in their northland has intrigued some Canadians for many years. More general national interest has been stimulated by a recent series of events: a sharper realization of the widening gap between known reserves and forecasted world needs for oil; the discovery of a vast deposit of oil near Prudhoe Bay, Alaska in 1968; and international developments which, since 1973, have disrupted the complex patterns of world trade in oil. The need for oil exploration in the Canadian Arctic, including the southern Beaufort Sea, is now considered in many quarters to have assumed vital importance. As a partial response to this feeling, the Beaufort Sea Project was undertaken in 1973 to assess the impact of any offshore drilling on the environment. The Project was funded jointly by the Canadian Government and the Oil Industry.

Proposed offshore exploration for gas and oil in the Canadian portion of the Beaufort Sea is at present limited to the wide shallow shelf extending from the Alaska border in the west to Cape Bathurst in the east, a distance of more than 400 kilometres (km).*

The objective of the Project was to provide government with background information to formulate guidelines such that offshore drilling in the area under consideration can be conducted in a fashion to minimize adverse effects to the environment, to the resident native population, and to the drilling operations themselves.

2. THE BEAUFORT SEA PROJECT

2.1 General

The Beaufort Sea Project (BSP) consists of co-ordinated studies, carried out in the southeastern Beaufort Sea during 1974 and 1975, to accomplish the following tasks:

a) to obtain oceanographic, biological and geophysical baseline data;

b) to predict the characteristics of the sea climate likely to be encountered during offshore drilling operations; and

c) to devise means of countering adverse environmental effects of accidental spills of oil or of other contaminants.

Thirty-nine technical and scientific reports tabulating and analyzing data obtained in the field or in the laboratory were prepared during 1974 and 1975. This report is an overview, providing

* Only metric units are utilized throughout this report. However, factors for metric-to-British and British-to-metric conversions are provided in Appendix A.

thorough assessment, interpretation and synthesis of the results of several of these reports.

2.2 The Present Overview

This overview examines the effects of the various oceanographic aspects of the Canadian Beaufort Sea upon waterborne pollutants. As general background it provides the following sections:

- a short summary of the efforts spent in obtaining geographic, hydrographic and oceanographic knowledge of the area prior to the Beaufort Sea Project. Rationales for the studies are also noted.

- a brief review of the physiography and physical geography, bathymetry, ice, relevant aspects of climatology, etc., (but not including physical oceanography).

- a summary of the present state of knowledge in respect to the physical-oceanographic features of the sea. The features include primarily the characteristics of water properties and motions.

- a resume of the types of pollutants that could be introduced into the environment in quantity as a result of oil drilling and associated activities. Included are the substances that would be discharged to ocean waters, as well as those that would be airborne.

The relevant information is used to generate a series of scenarios incorporating various combinations of oceanographic and meteorological conditions most likely to be encountered in the area throughout the year. The extremes associated with the conditions are also noted. The prime objective of the scenarios is to suggest the influence of each of several relatively-common combinations of conditions upon the transport, and the eventual fate, of oil or of other pollutants introduced into the southeastern Beaufort Sea. Some of the important possible consequences to the biology of the area are briefly noted. Such knowledge should contribute to the prevention, or at least the minimization, of damage resulting from offshore drilling. Examination of the scenarios should also aid in determination and/or refinement of procedures that will maximize the safety of oil-drilling operations against environmental assault.

Much of value has been learned during the Beaufort Sea Project regarding the mechanisms affecting both the transport and the fate of waterborne pollutants released into the arctic environment. However, significant deficiencies in the knowledge about such mechanisms still exist. A listing of what are believed to be the primary aspects upon which further study is essential is provided.

3. THE REGION UNDER STUDY - GENERAL BACKGROUND

3.1 Definition

The "Beaufort Sea" is the name traditionally applied to the waters which lie off the northern coast of Canada and the United

States between the Chukchi Sea to the west and Banks Island to the east (Figure 1). The International Hydrographic Bureau considers the northern boundary of the Beaufort Sea to be the line joining Point Barrow, Alaska and Cape Lands End on Prince Patrick Island. The area was named in 1826 for the then Hydrographer to the British Admiralty, Sir Francis Beaufort (the originator of the Beaufort wind and weather scale). The sea is an integral part of the Arctic Ocean, and there is no strong physiographic or oceanographic justification for separate identity; nevertheless, the name is now firmly established in the geographic nomenclature.

This report is concerned primarily with the southeastern portion of the Beaufort Sea, i.e. that portion east of the northward extension of the boundary between Canada and Alaska and south of Cape Prince Alfred (the northwest tip of Banks Island). The area is in contact with waters to the east through two passages; 1) to the south, through Amundsen Gulf, and 2) to the north through M'Clure Strait. The adjoining coastal areas are also considered.

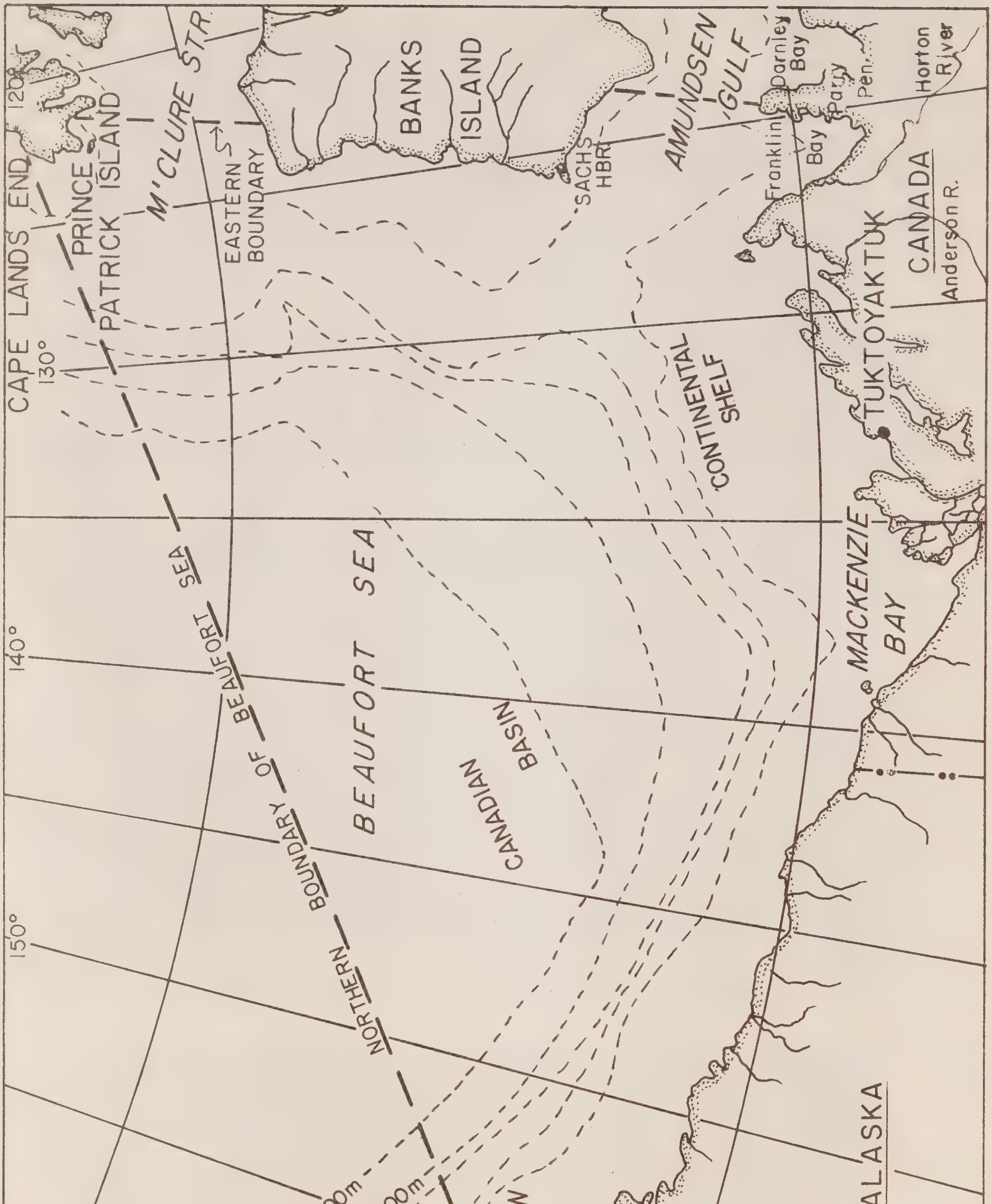
The region under examination by the project encompasses a large number of exploration leases owned by various oil companies or consortia (Figure 2). It is considered to be totally within Canadian sovereignty.

3.2 Principal Investigations Previous to the Beaufort Sea Project

The earliest ventures into the Beaufort Sea region were initiated with markedly different objectives than the exploitation of resources. The majority of the geographical explorations were carried out from the 16th to the 19th centuries and were primarily attempts to find a northwest passage. Several fisheries were also exploited. Hydrographic charting has been undertaken primarily to ensure the safety of shipping that services the southwestern Arctic. Oceanographic investigations have been carried out to obtain knowledge for various theoretical and applied researches upon the area. Most of the hydrographic and oceanographic studies have been carried out since the end of World War II.

3.2.1 Geographic Exploration

A sea route to the Pacific from Europe was a longtime dream of seafarers. Initially, the search was motivated by commercial interests; during the 16th century, the wealth then flowing to Spain and Portugal from their American possessions made the rest of Europe increasingly anxious to find a sea route to the treasuries of the East. A search, which was to continue with varying intensity for over 300 years, began with the object of finding a passage either to the northeast along the northern coasts of Europe and Asia, or to the northwest along "the back of America" - the so-called northwest passage. The history of the exploration of the Beaufort Sea is an integral part of the history of the search.



CAPE LANDS END
PRINCE PATRICK ISLAND
M'CLURE STR.
BANKS ISLAND
EASTERN BOUNDARY
SACHS HBR.
AMUNDSEN GULF
Darnley Bay
Franklin Bay
Parry Pen.
Horton River
CANADA
Anderson R.
TUKTOYAKTUK
CONTINENTAL SHELF
NORTHERN BOUNDARY OF BEAUFORT SEA
BEAUFORT SEA
CANADIAN BASIN
MACKENZIE BAY
ALASKA
POINT BARROW
3000m
2000m
1000m
500m
200m
75°
70°
120°
130°
140°
150°

Figure 1

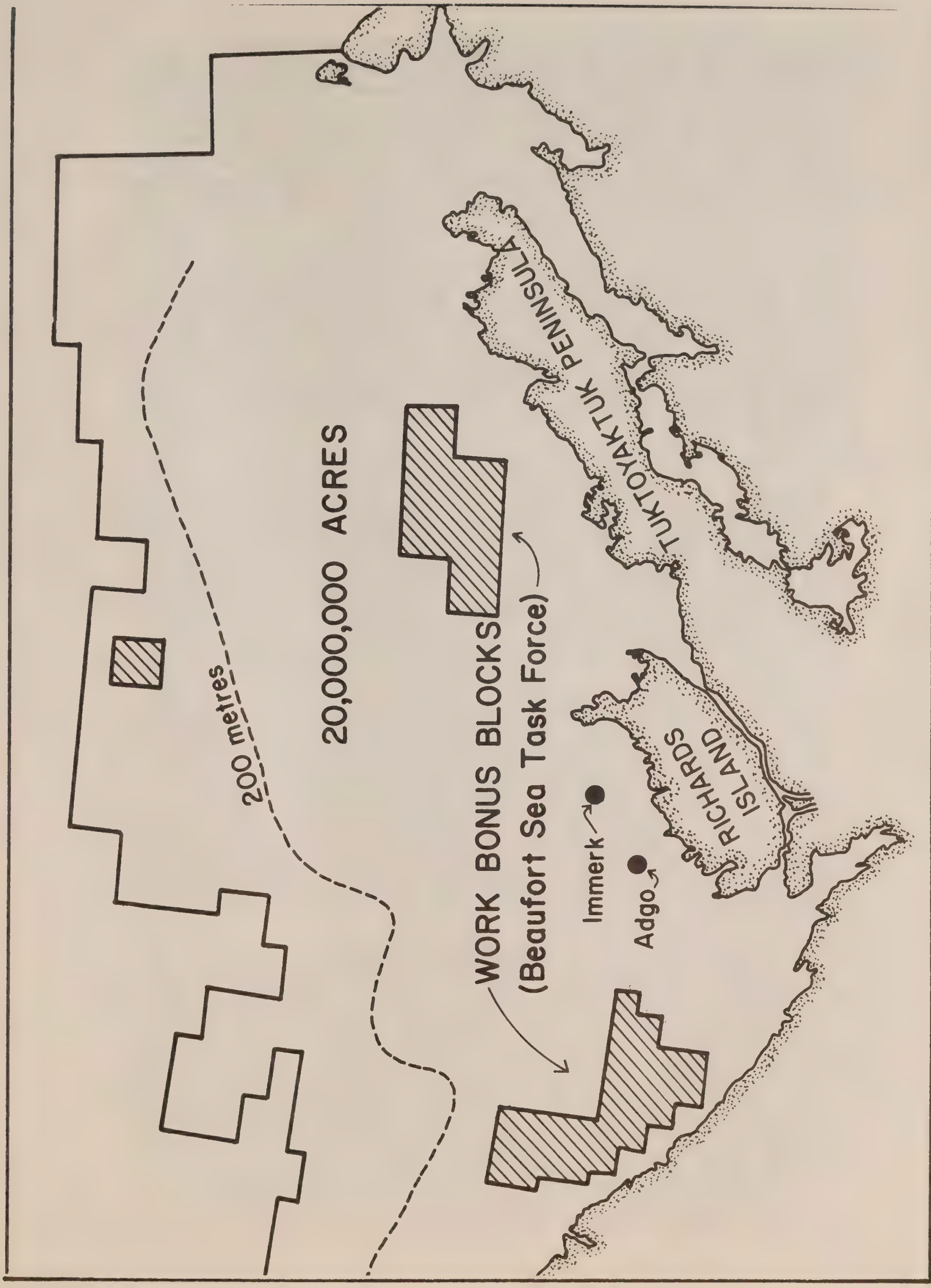

20,000,000 ACRES
WORK BONUS BLOCKS
(Beaufort Sea Task Force)
200 metres
TUKTOYAKTUK PENINSULA
RICHARDS ISLAND
Immerk
Adgo

Figure 2

The great chartered trading companies of England were outstanding among the 16th-and 17th-century sponsors of exploration. These enterprises were interested in finding safe sea routes to the Orient, other than those which lay exposed to Spanish or Portuguese attack around Cape Horn or the Cape of Good Hope. From time to time, they either sent out experienced members of their own merchant fleets or were persuaded to lend financial and political backing to voyages of discovery undertaken by outstanding seamen of the period.

Through the efforts of the men engaged in the quest for the northwest passage, much was learned about Hudson Bay and the waters of the eastern end of the Canadian Archipelago; attention was also drawn to the potential of various fisheries such as those for whales and cod within this area. However, the voyages failed to find a northwest passage. Interest in the passage therefore waned, and was not to be revived for about 50 years.

After 1815, the scientific community in England fortuitously succeeded in re-interesting the Admiralty in Arctic exploration. Stress was placed upon scientific, as well as upon purely exploratory, aspects. During the period 1818 - 1849, a number of expeditions obtained knowledge of the Arctic greater than the entire amount gained previously. The activity during this period included the first major expedition to the Beaufort Sea by a party commanded by Captain John Franklin of the Royal Navy. This was Franklin's second expedition to the Arctic.

It left the United Kingdom in 1825 and returned in 1827. (The objective of both expeditions was the continued exploration of the North America Mainland coast from Coppermine to Icy Cape, Alaska.) The party travelled to New York, then overland to Fort Chipewyan and followed the Mackenzie River to its mouth, arriving there on 18th August, 1825. The group wintered at Fort Franklin on Great Bear Lake. The following year, one part of the group moved west from the Mackenzie Delta to Return Reef, Gwydyr Bay, Alaska, while the remaining men journeyed east to Coppermine and thence to Fort Franklin on foot.

In 1826 the Hudson's Bay Company decided to send two of its experienced men, Peter Dease and Thomas Simpson, to complete the survey of the mainland coast. After a 3,200-km journey overland from Fort Garry (now Winnipeg) on the red River, Dease and Simpson reached the mouth of the Mackenzie and pushed westward along the coast past Return Reef until stopped by ice at Cape Simpson; this Cape was named after George Simpson, Governor of all the HBC Territories. From Cape Simpson, Thomas Simpson (no relation to George) set out on foot with a small group and reached Point Barrow on August 4th, 1837.

The exploration of the mainland coastline of the Beaufort Sea from Point Barrow to Cape Bathurst was now complete.

In 1845 the Admiralty mounted yet another Franklin expedition, this one to find, and to attempt the navigation of, the northwest passage. It was realized that such a passage was now of negligible commercial value, but nonetheless, considerable prestige would accrue from its successful navigation. Moreover, the learned societies in England welcomed and supported the opportunity of obtaining extensive Arctic observations, and a considerable quantity of scientific instruments was placed aboard the ships of the expedition. The expedition was equipped for a three-year stay in the Arctic; therefore serious concern for its safety was not felt until 1849. No information from or about the expedition having been obtained to this time, concern began to mount, and numerous relief expeditions were launched until 1859. At that time definite news was received which explained the fate that had befallen the Franklin party; all 127 men had perished in the Arctic. Although the voyages launched during this period had, of course, as their principal task the search for Franklin, they generally added at the same time an immense amount of new knowledge to the cartography of the Canadian Arctic.

Perhaps the most notable of these expeditions, from the point of view of Beaufort Sea Exploration, was the three-ship party sent out from England in 1850 by way of the Straits of Magellan, the Pacific Ocean and Bering Strait. One ship under Commander Robert M'Clure, RN, moved into the Arctic and headed northeast. It was beset by polar ice in Prince of Wales Strait. Sledge parties from the ship surveyed the northeast coast of Banks Island in the spring of 1851. The ship was released by the ice in July 1851, but was unable to proceed further north through Prince of Wales Strait; it then came south and west about Banks Island, reaching the northern shore in September. The vessel then became permanently frozen in. By virtue of abandoning the ship and subsequently being picked up by a search vessel which had arrived by way of the eastern Arctic, M'Clure and his crew were able - after much controversy - to claim a large monetary prize offered by the Admiralty for the discovery of the northwest passage. Thus by 1852, the only remaining unsurveyed coastline in the Beaufort Sea was that of Prince Patrick Island. That year, the British government set out its last and greatest Franklin search expedition under the command of Sir Edward Belcher. The objectives were two-fold; firstly, to continue the search for Franklin, and secondly, to seek the expedition involving M'Clure and his colleagues, for whose safety there had arisen a growing anxiety. During the course of the expedition, one of the junior officers, Lt. Mecham, after a sled journey of about 1,850 km , became the first European to set foot on Prince Patrick Island; he charted the island south to about Discovery Point. Lt. McClintock of the same party as Mecham, after an even more epic sled journey (about 2,200 km) travelled north on the island as far as the northwest point, Cape Leopold McClintock (approx. 77° 30'N, 116° 40'W).

The 10-year period of searches for Franklin resulted in the almost complete charting of the Beaufort Sea coast line. It was not until almost 60 years later that the Canadian Arctic Expedition of 1914-1918, under Vilhjalmur Stefansson, surveyed the last unmapped stretch of coast between Discovery Point and Cape Leopold McClintock, thus completing the survey of the Beaufort Sea coast line. The Stefansson expedition also inhabited a drifting icefloe for about six months, and was able to disprove the existence of any land within the main body of the Beaufort Sea.

M'Clure had proven the existence of a northwest passage, but at that time its commercial application was worthless, and therefore no further major expeditions were outfitted. However, it may be noted that the challenge of making the passage by ship remained. That challenge was met first by Roald Amundsen, who in 1905 sailed from Norway in a 47-ton herring boat, the *Gjøa*, and completed the east-west trip through the passage by the summer of the following year.

This passage was not traversed again until World War II. The RCMP Schooner *St. Roch*, under the command of Sergeant H.A. Larsen, sailed the passage, from west to east, during the course of two years (1940-42). In 1944, Larsen provided his own "first" by navigating the passage in a single season, going from Halifax, Nova Scotia to Vancouver, British Columbia.

The first deep-draft ship to accomplish the northwest passage was the Canadian icebreaker, HMCS *Labrador*, which in 1954 made the west-to-east passage.

3.2.2 Hydrographic Charting

The first systematic attempts at hydrographic charting of the Beaufort Sea were carried out by Stefansson during 1914 to 1918. By taking soundings through natural openings in the ice every 65 to 80 km offshore from the Alaska coast, Stefansson was able to show that the bottom of the Beaufort Sea was not merely an extension of the shallow continental shelf, as had been previously believed. The depths at most locations were found to be greater than about 1,400 metres (m). (Depths exceeding this value could not be determined, as the longer sounding wire originally planned for use had been lost early in the expedition, in the sinking of one of the party's vessels.)

The next significant phase of the hydrographic charting of the Beaufort Sea was carried out primarily for navigational purposes and involved nearshore waters, in particular the more important harbours and anchorages. What activity occurrred in the Beaufort Sea between the two World Wars was concerned with the survey, in 1930-32, of Tuktoyaktuk Harbour - which is situated at the eastern end of the peninsula of the same name - and some reconnaissance sounding carried out between Herschel

and Pullen Islands in 1933. From information provided by masters in the HBC Service, the Canadian Hydrographic Service (CHS) published several large-scale charts of the more important harbours and anchorages in use throughout the Beaufort Sea in the early 1950s. (The HBC had for several years supplied its trading stations in the western Arctic by means of ships sailing from Vancouver and Victoria, British Columbia.)

During the early 1950s, Canada and the United States carried out a co-operative study in western Arctic waters. In 1950, soundings by the icebreaker U.S.S. *Burton Island* (Figure 3) determined the approximate position of the continental slope of the Beaufort Sea; the existence of a canyon in the vicinity of Herschel Island was also suggested. In 1951, both the American vessel and the Canadian research ship *Cancolim II* (Figure 3) engaged in further hydrographic work, with the latter concentrating upon a survey of the Mackenzie Canyon, the continental shelf, and the west coast of Banks Island. In 1952, the *Cancolim II* obtained further hydrographic sounding data, primarily on the shelf of the Beaufort Sea. Depositional processes associated with the Mackenzie River outflow were inferred.

The demand for hydrographic information in the Beaufort Sea accelerated markedly from about 1955, at which time military considerations regarding the defence of North America against attack from "across the North Pole" had dictated the construction of a defence warning system in the arctic. Materials for construction and for supply of sites on the DEW (Distant Early Warning) Line - a 5,800 km long chain of radar stations stretching from western Alaska to Greenland - had to be transported primarily by ship, and the inadequacy of existing navigational charts for this purpose necessitated prompt action.

The initial impetus came from the United States: United States Hydrographic Office (USHO) teams surveyed the approaches to the sites of the DEW line stations, while American vessels sounded the proposed shipping route from Herschel Island to the Central Arctic Ocean. By 1957, charts of the Beaufort Sea showed a safe shipping track east from Point Barrow. The CHS had meanwhile completed a two-season standard survey of Tuktoyaktuk Harbour.

In 1960, the Canadian icebreaker CCGS *Camsell* commenced operations in the western Arctic, and hydrographers on board added to the charts of the Beaufort Sea as the ship carried out her icebreaking duties in support of the ships supplying the DEW line. However, in 1962, the CHS commissioned the CSS *Richardson* for work in the Arctic. For the first time, the CHS had its own vessel from which to conduct hydrographic surveys, and no longer had to depend on other agencies providing ship time on an "opportunity" basis.

3a

3b

Courtesy F.G. Barber

Figure 3

Mention must also be made of the efforts of the Polar Continental Shelf Project (PCSP) which was established in 1959. Scientists associated with this project developed and refined methods of sounding through ice in areas inaccessible to ships.

The discovery in 1968 of oil at Prudhoe Bay on the northern slope of Alaska, coupled with the rapidly increasing need for energy, heralded yet another era of marked activity in the hydrographic surveying of the Beaufort Sea. In 1969, the supertanker USS *Manhattan* sailed from the eastern United States to the oil field area of the Alaskan Northern Slope - testing the feasibility of using the northwest passage to transport Arctic oil to the east coast of the United States. Her escort, the Canadian icebreaker CCGS *Sir John A. Macdonald,* discovered a shoal in the open Beaufort Sea - which had until then been considered a safe area for normal draft vessels. The potential use of deep-draft vessels indicated the need for a major updating of the existing hydrographic charts, and in 1970 the CHS mounted a concentrated surveying effort in the area. The CSS *Parizeau* and the CSS *Baffin* worked offshore north of the Tuktoyaktuk Peninsula; this program continued with CSS *Parizeau* during the 1971 and 1972 seasons.

Hydrographic and natural resource charting was also undertaken during this period - commencing in 1970 when the CSS *Hudson,* on the final leg of her historic HUDSON '70 cruise, worked the Beaufort Sea. (The honour of the first circumnavigation of the entire American continent - North <u>and</u> South America - fell to the *Hudson* on this cruise.)

3.2.2 Oceanographic Studies

With one exception, oceanographic studies within the Beaufort Sea have been conducted subsequent to World War II. The single earlier effort was carried out from the RCMP schooner *St. Roch* while she was on patrol duty in the Canadian Arctic in 1935 and 1937. Surface physical characteristics were measured at locations in the southern nearshore waters of the Beaufort Sea - as well as in the northern Bering Sea, Bering Strait, and the Amundsen Gulf "system" to about 480 km east of the Beaufort Sea. Some collections of biological material were also made.

Sampling was carried out west-to-east in 1935 and east-to-west in 1937.

No significant further oceanographic work was undertaken until 1950. During that year, 21 stations were occupied in the southern Beaufort Sea by the American icebreaker USS *Burton Island,* 19 of these in Canadian waters. During the following year they occupied 42 stations, 28 of them in Canadian waters. (Unfortunately, these data were collected too far offshore to be of much use to the Beaufort Sea Project.)

In 1951, the *Cancolim* II expedition occupied 43 oceanographic stations in Canadian Beaufort waters - primarily over Mackenzie Canyon, the western end of Amundsen Gulf, and off the Mackenzie Delta and the west coast of Banks Island. Standard oceanographic depths to as great as about 500 m were sampled. Some biological and geodetic work was also carried out.

In 1952, 182 oceanographic stations, which included bathythermograms (BTs), were occupied by the *Cancolim* II - all within the southeastern Beaufort Sea from Herschel Island to Amundsen Gulf. Depths as great as 600 m were sampled. The predominance of wind and of Mackenzie River outflow in establishing at least the surface physical oceanographic regime of the area was established.

In 1954, the co-operative United States-Canada study of the Beaufort Sea and adjacent waters culminated in an investigation of the Canadian Beaufort Sea, Amundsen Gulf, and M'Clure and Prince of Wales Straits; two American vessels and one Canadian vessel took part.

From summer 1959 through winter 1959-60, oceanographic stations were taken from Ice Island T-3 (see Section 4.2.1). In 1970 physical- and biological-oceanographic data were obtained over the shelf of the Beaufort Sea.

All the previously-noted oceanographic work was carried out during the summer season - at which time the extent of the Arctic pack ice is generally at an annual minimum. The only significant amount of winter data in the Beaufort Sea was obtained in late March and early April, 1972, at which time several stations on the ice were occupied by helicopter.

From the above and other data, the basic regime of oceanographic properties in the Beaufort Sea has been enunciated; in addition, the field of motion to considerable depths has been inferred.

The amount of direct measurements of water movement in the area remains meagre. To 1974, the primary source of such measurements has been the various ice islands - occupied for various periods by scientific personnel of the U.S. or of the U.S.S.R. - and well-known as Fletcher's Island (T-3), ARLIS II, North Pole (NP6, -7) etc. Study of the drift of these islands in the northern Beaufort Sea (generally north of about 70°N) has been fundamental in defining the so-called Beaufort Sea Gyre, which is the primary characteristic of the shallow circulation in the area (see Section 4.2.1). In addition, a few current profiles to appreciable depths have been obtained. In August, 1965, measurements of currents from the surface to about 3600 m - very near the bottom - were obtained from Ice Island T-3 near 71°N, 140°W.

Currents to 300 m were measured at two locations during the AIDJEX (Arctic Ice Dynamics Joint Experiment) project carried out by the U.S. in 1971 and 1972. In the former year, data were obtained about 150 km to the west of the northwest tip of Banks Island, and in the latter, about 180 km north of the Mackenzie Delta. In 1970, measurements of "surface" (1.5-m) and 10-m currents were carried out, by means of drogues, off the Mackenzie River Delta and the Tuktoyaktuk Peninsula as far east as Atkinson Point.

It may also be noted that physical-oceanographic studies in the eastern and central Canadian Arctic (including the connecting passage to the Beaufort Sea) commenced as early as 1928. To this writing, this effort has been more intensive than has that in the western Arctic. Attempts have been made to define the relationships between the water properties within the eastern Arctic and those characterizing the Beaufort Sea.

3.3 The General Physical Environment

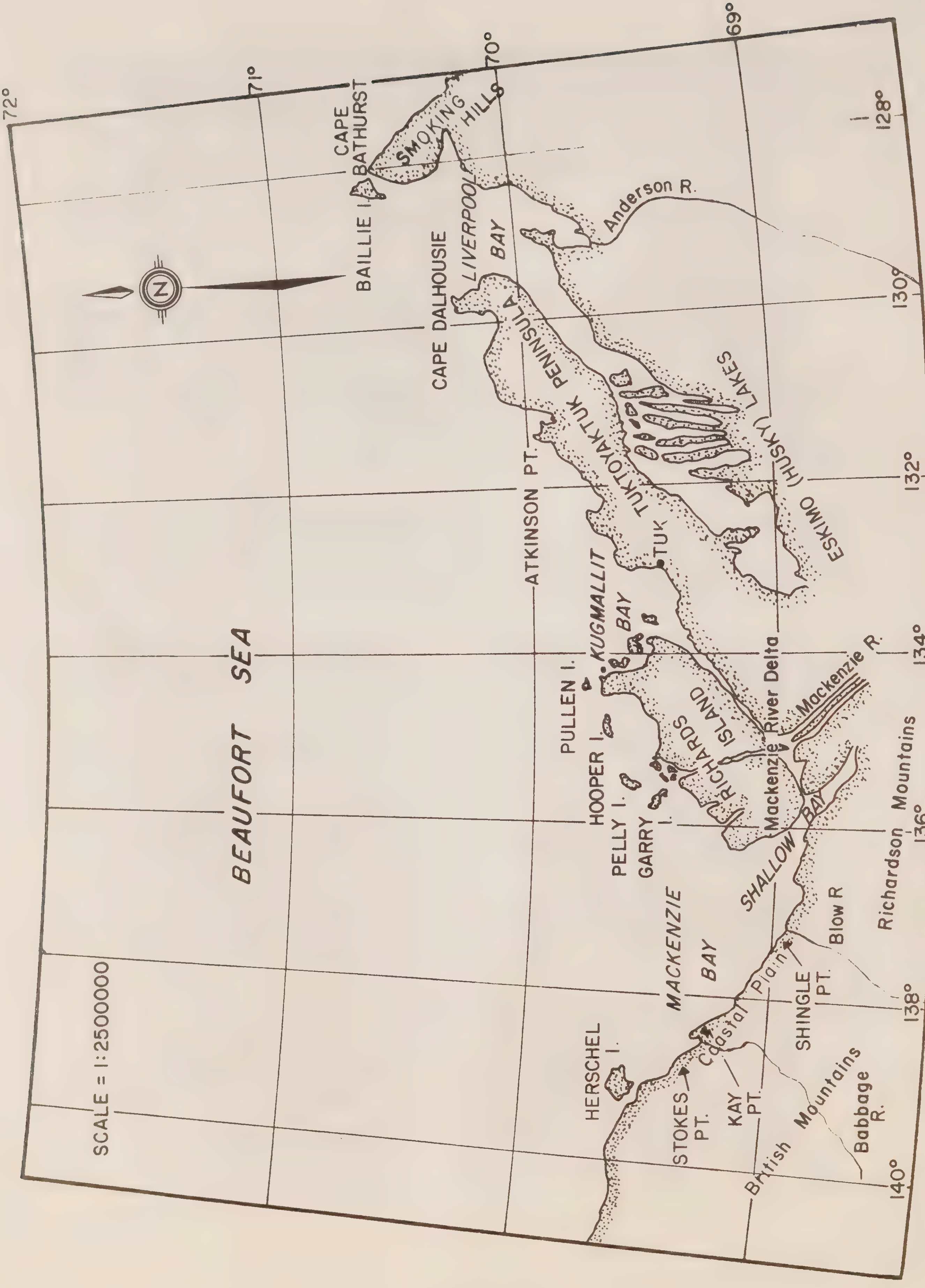
The various aspects of the physical environment of the Beaufort Sea, as deduced from the studies noted in the previous subsection, can be briefly summarized.

3.3.1 Regional Physical Geography

The mainland coast of the Beaufort Sea is comprised of two principal physiographic divisions: a low coastal plain and the delta of the Mackenzie River (Figure 4).

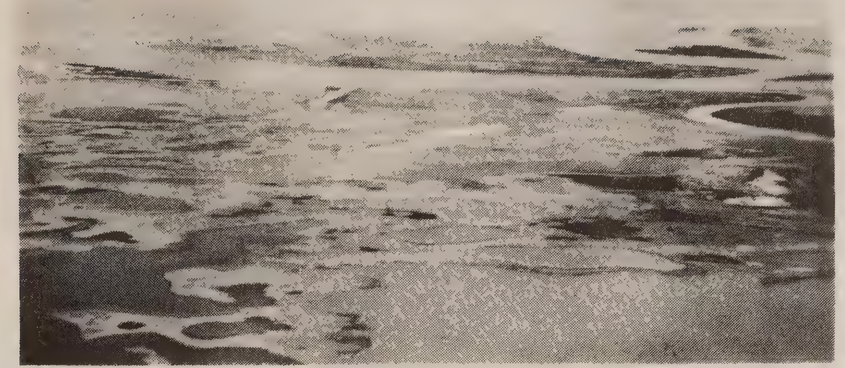
The coastal plain is widest in the vicinity of Point Barrow, Alaska - approximately 250 km. It narrows considerably toward the east so that along the arctic coast of the Yukon Territory it is only 15 to 30 km wide; it is backed abruptly by - from west to east - the British, Buckland, Bain and Richardson Mountains, at distances of 25 to 50 km inland. The Yukon coast is characterized by several distinctive features, such as stretches of low but steep coastal cliffs about 6 to 12 m high, containing ground ice and fronted by narrow beaches, spits and barrier beaches up to 10 km long and a few hundred metres wide.

The most distinctive landmarks on the plain itself are the wide beds of broad and braided streams, such as the Babbage and Blow Rivers (Figure 5a, b) which flow from the backing mountains across its nearly level extent. The sediments brought down by these rivers are building up partially-vegetated deltas, sand-spits, lagoons and low alluvial islands. The principal neighbouring island is Herschel Island at about 139°W.



BEAUFORT SEA
SCALE = 1:2500000
N
72°
71°
70°
69°
128°
130°
132°
134°
136°
138°
140°
CAPE BATHURST
BAILLIE I.
SMOKING HILLS
CAPE DALHOUSIE
LIVERPOOL BAY
Anderson R.
TUKTOYAKTUK PENINSULA
ATKINSON PT.
ESKIMO (HUSKY) LAKES
TUK
KUGMALLIT BAY
PULLEN I.
HOOPER I.
PELLY I.
GARRY I.
RICHARDS ISLAND
Mackenzie River Delta
Mackenzie R.
SHALLOW BAY
MACKENZIE BAY
Richardson Mountains
Blow R
SHINGLE PT.
Coastal Plain
HERSCHEL I.
STOKES PT.
KAY PT.
British Mountains
Babbage R.

Figure 4



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GSC 202717-J

Figure 5

The covering on the plain consists of a thick mantle of unconsolidated deposits (Figure 6a). Permanently frozen ground (permafrost) exists not far below the surface (Figure 6b) - at most a few metres during the summer. Poor downward drainage of surface waters results in meandering streams, swamps, and the bogs or marshes known as "muskegs". Trees grow near the river banks, but are not generally prevalent elsewhere on the plain.

The continuity of the coastal plain is interrupted by the waterlogged Mackenzie Delta, an intricate maze of alluvial banks, islands and shallow lakes separated by meandering channels (Figure 7). This delta, one of the largest in the world, extends approximately from the eastern end of the southward-trending Richardson Mountains (longitude about 135°W) to the eastern side of Richards Island, which forms the major portion of the delta. Several small islands, among them Pelly, Hooper, Garry and Pullen, are located just off the delta. As a result of spring floods and of consequent redepositions of the sediments discharged by the Mackenzie River, these features may considerably alter their shape and orientation over a period of a few years. (Some of the characteristics of Mackenzie River flow are discussed in Section 3.3.2.) The delta is very low lying except for some of the islands at the northern end, which have an elevation of about 30 m. Along its western edge, the southern limits of the coastal plain rise above it in sheer cliffs 30 to 60 m high; the eastward-flanking Caribou Hills, of height of about 150 m, have a sharp western face.

The continuation of the low coastal plain, extending eastward from the Mackenzie Delta past the prominent, more than 160 km long Tuktoyaktuk ("Tuk") Peninsula towards the Baillie Islands and Nicholson Peninsula (Cape Bathurst), is bordered to the north by extensive shoals, spits and sandbars (Figure 8a, b).

The coastline is extremely complex as a result of the gradual sinking of the markedly lake-strewn, almost level area. The only distinctive elevations from seaward are provided by a few low conical hills, called "pingos", located a short distance inland and rising to 30 to 60 m in height. Pingos are ice-cored mounds of sediment. The Anderson is the primary river crossing this portion of the plain.

The Tuktoyaktuk Peninsula is bounded to the south by Liverpool Bay and by a southwesterly continuation of this Bay more generally known as Eskimo Lakes. In contrast to the Yukon coast, the northern shorelines of both Richards Island and the Tuktoyaktuk Peninsula are characterized by deep embayments caused by the breaching of thermokarst lakes. (These lakes, which form in depressions caused by melting ground ice, are particularly common on the delta.)

Southward for a distance from Cape Bathurst, the bold western shore of Franklin Bay is formed of mud and unconsolidated


GSC 202959-Y


GSC 202959-K

Figure 6

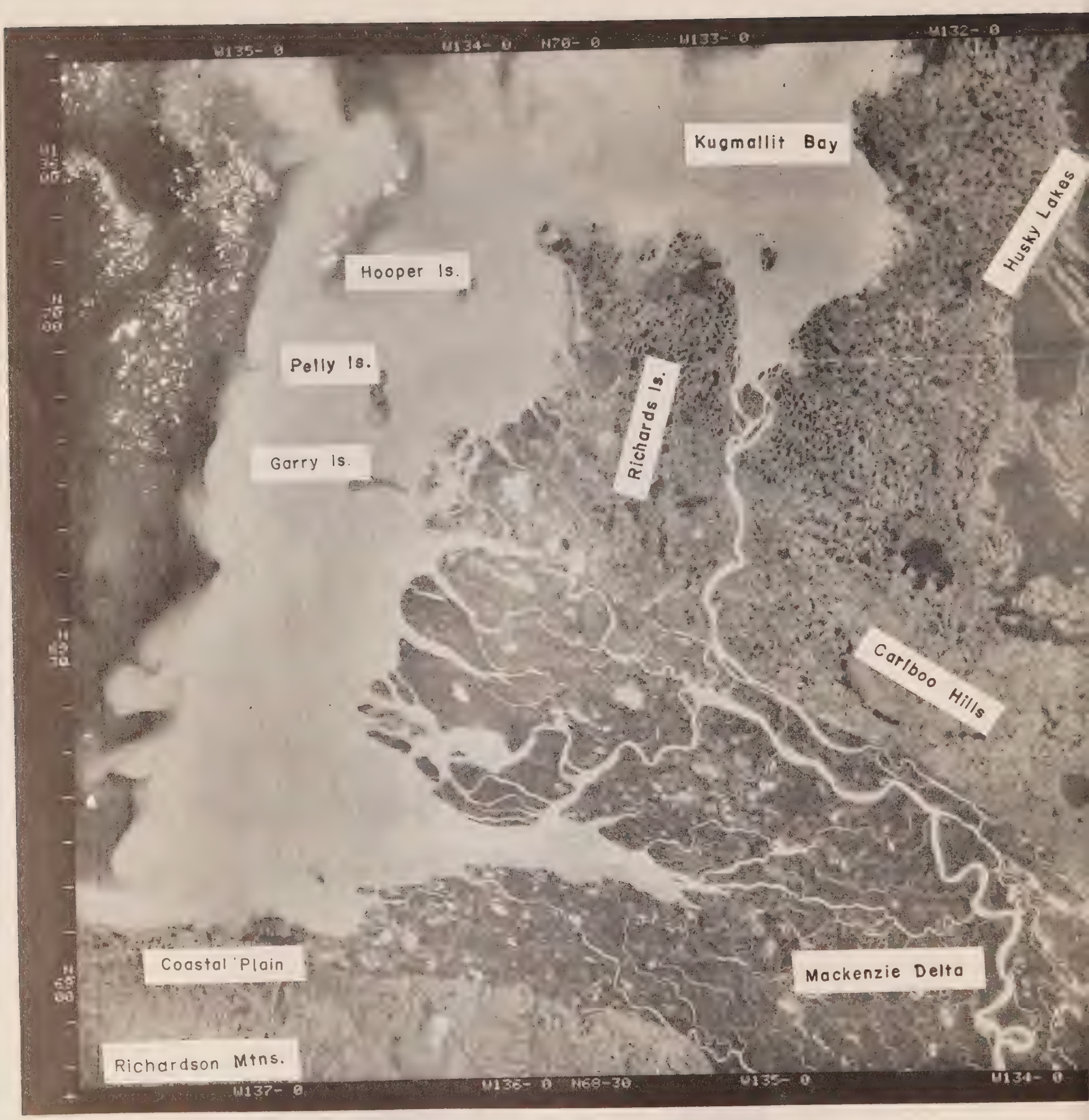

W135- 0
W134- 0
N70- 0
W133- 0
W132- 0
Kugmallit Bay
Husky Lakes
Hooper Is.
Pelly Is.
Richards Is.
Garry Is.
Cariboo Hills
Coastal Plain
Mackenzie Delta
Richardson Mtns.
W137- 0
W136- 0
N68-30
W135- 0
W134- 0

Figure 7

8a

GSC 202773-S

8b

Figure 8

materials, which, over long stretches, fall to the sea in cliffs; these features, although sheer, are sometimes not more than 15 m high. In the vicinity of Fitton point, elevations rise to approximately 60 m; southward of this, the higher coast is formed by the line of the Smoking Hills. Towards the end of the bay these hills retreat some distance inland, merging with the western limits of the Melville Hills which have heights greater than 300 m. These steep cliffs have crumbled in many places; however, even where the high banks have retreated inland and the land now slopes to the sea instead of falling sheer, this western coastline of Franklin Bay remains well defined. The Horton River, of appreciable size, enters the Beaufort Sea at the western side of the mouth of Franklin Bay.

Parry Peninsula, separating Franklin and Darnley Bays, rises from a low drift-strewn isthmus, dotted by many shallow lakes, to attain a height of about 60 m near its northern limit; here outcrops of limestone form steep cliffs 24 to 30 m high, both on the tip of the peninsula and on the offshore islands. These cliffs have been eroded by sea action into an intricate confusion of arches, caves, inlets and islands, with underwater reefs making water treacherous for navigation in many areas. Southward from this, the offshore waters again become shallower, and spits, shoals and mudbanks fringe the coast.

Banks Island, which marks an eastern limit of the Beaufort Sea, is the most westerly island of the Canadian Archipelago, and has an area of about 60,000 km^2. Coasts are bold along the north and south (Figure 9a). However, the western shoreline (that facing the Beaufort Sea) is low and irregular, marked by coastal bars, spits and shallow waters for a considerable distance offshore similar to Figure 9b. The land in this area appears to be subsiding, and the drowned shoreline is somewhat reminiscent of that of the arctic mainland east of the Mackenzie Delta.

3.3.2 The Mackenzie River

The primary watercourse on the mainland facing the Beaufort Sea is the Mackenzie River. This river, one of the world's longest, is more than 4,100 km in length, and its drainage area is about 1,900,000 km^2 in extent. The river drops fairly steadily from an elevation of about 170 m at its source, Great Slave Lake. The Great Bear, Liard, Nahanni, Keele, Arctic Red and Peel Rivers are major contributors to the final outflow of the Mackenzie.

The delta of the Mackenzie comprises myriad of interwoven channels (Figure 10), some of which can be flooded or dry according to the time of year. At all times, by far the largest percentage of the river water entering the delta moves down the Middle Channel. This percentage appears to display a seasonal variation of about 9% (about 94% in winter vs about 85% in summer). The significantly larger flow occurring in winter

9a

9b

Figure 9


KUGMALLIT BAY
TUK
ISLAND
RICHARDS
MIDDLE
LAKES
ESKIMO
SHALLOW
REINDEER CH.
EAST
CHANNEL
BAY
CHANNEL
WEST
CHANNEL
INUVIK
CHANNEL
AKLAVIK
MIDDLE
KALIMEK
CHAN.
PEEL CH.
PEEL
RIVER
MACKENZIE
RIVER

Figure 10

may be attributable to the fact that many of the smaller channels freeze to the bottom or are blocked by slush ice; flow through them therefore ceases or is much reduced, water being diverted into the major channels. Several lesser channels, such as the Kalinek and the Peel, handle the remainder of the flow into the delta.

The river outflow enters the Beaufort Sea itself through several channels - and therefore does not strictly constitute a "point source" of fresh water to the sea. However, brief studies conducted in winter have indicated that the distribution within the various channels can differ markedly from that occurring at the southern limit of the delta and noted just previously. The results suggest that, during winter at least, about 33% of the total flow moves into Kugmallit Bay through the East Channel, east of Richards Island; about 28% flows down the west side of Richards Island (with 20% staying in the middle channel through to Mackenzie Bay), and about 38% moves into Shallow Bay and therefore Mackenzie Bay through Reindeer Channel.

The outflow from the Mackenzie River System is strongly seasonal in nature (Figure 11). The spring freshet commences generally in early May, and attains a peak flow of approximately 26,000 m^3/sec from about the middle of May to the beginning of June. From this time until August, the discharge can vary by as much as 6,000 to 8,000 m^3/sec within a period of a few days. This variability is probably due to the passage of weather systems through the drainage area of the Mackenzie River complex. The flow then declines irregularly to the succeeding winter's minimum (of the order of 3,000 m^3/sec), which is usually attained by about the end of December.

The discharge into the Beaufort Sea, at least during the freshet season, is about 15% greater than that entering the Mackenzie Delta; the increase is perhaps due primarily to the addition of groundwater. The Mackenzie outflow provides the only fresh water source of general significance to the Beaufort Sea as a whole. Other sources are relatively minor and are of importance only in the immediate vicinity of their discharges.

By way of comparison, the Fraser, the major river on Canada's west coast, has a length of some 1,350 km and a drainage area of about 230,000 km^2; the outflow varies seasonally, generally between about 10,000 m^3/sec during freshet (in late spring and early summer) and about 1,000 m^3/sec in winter. Thus the Mackenzie is appreciably greater than the Fraser in every major characteristic.

Much sediment (primarily minerogenic in nature) is brought down by the Mackenzie River, by far the greatest amount during the freshet season. The settling of the larger suspended material is believed seaward and eastward from the mouths of the river (Section 3.3.3).

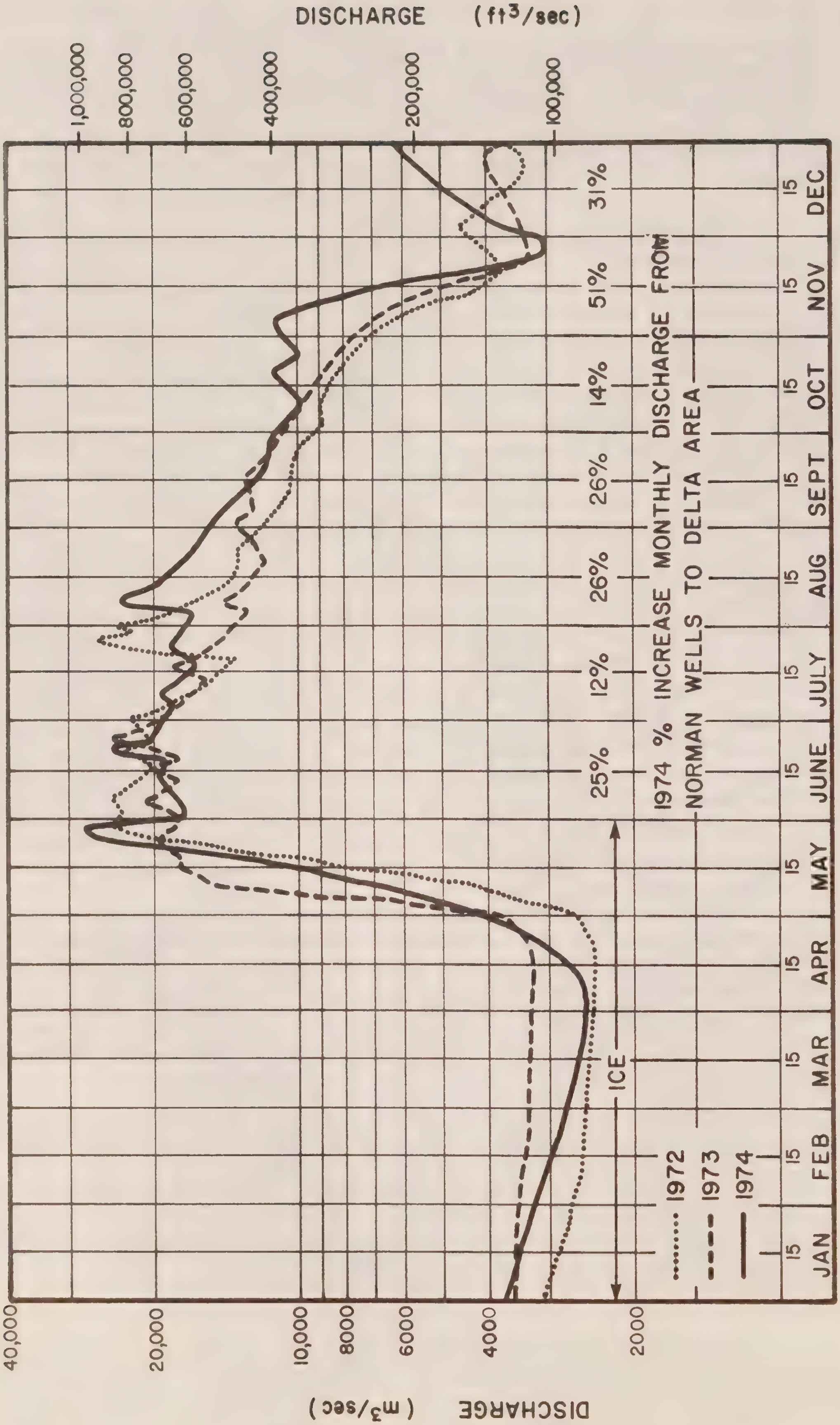

DISCHARGE (ft³/sec)
1,000,000
800,000
600,000
400,000
200,000
100,000
DISCHARGE (m³/sec)
40,000
20,000
10,000
8000
6000
4000
2000
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC
15
ICE
1972
1973
1974
1974 % INCREASE MONTHLY DISCHARGE FROM
NORMAN WELLS TO DELTA AREA
25%
12%
26%
26%
14%
51%
31%

Figure 11

3.3.3 Bathymetry

The Arctic Ocean in General

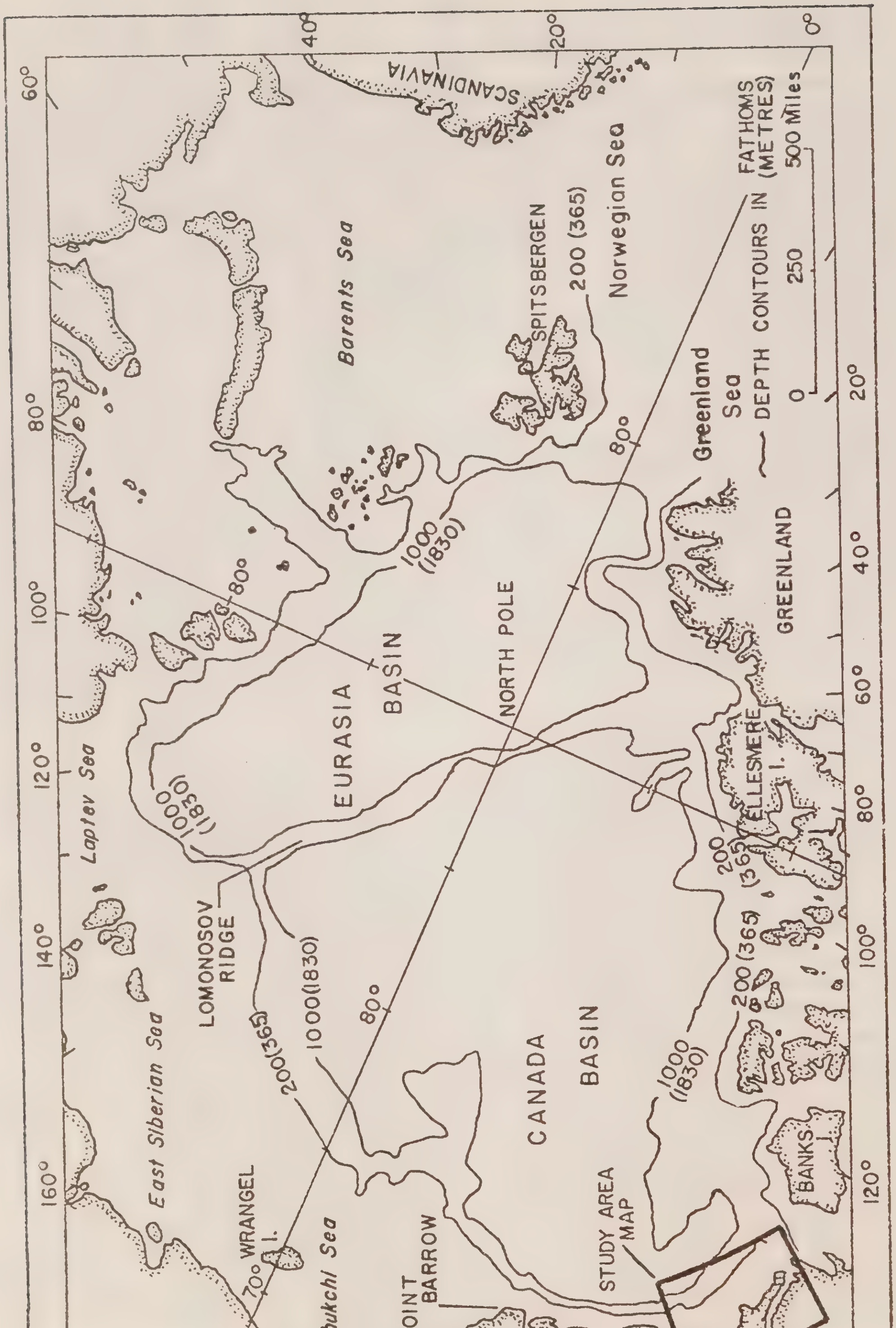
The Arctic Ocean, of which the Beaufort Sea constitutes a part, is surrounded primarily by the Eurasian Continent, Greenland, Alaska, the Canadian mainland and the islands of the Canadian Arctic Archipelago (Figure 12). Its major connection to the waters of the Atlantic Ocean (the Norwegian and Greenland Seas) is via the Greenland-Spitsbergen gap - 460 km wide and having a sill depth of more than 2,500 metres. Connection with the Pacific Ocean (the Bering Sea) is slight, being through Bering Strait which is only about 48 km wide and has a sill depth of but 50 metres.

The main basin of the Arctic Ocean is divided bathymetrically (i.e., by bottom topography) into two major sub-basins. The division is affected by the Lomonosov Ridge, an underwater mountain range extending from Ellesmere Island practically over the North Pole to Siberia. This ridge has a minimum depth of about 900 m, and a sill depth of about 1,500 m. The two major sub-basins are termed the Canada Basin (depth about 3,800 m) and the Eurasia Basin (depth about 4,200 m). The Beaufort Sea overlies the southernmost portion of the Canada Basin, as well as a portion of the adjoining North American Arctic Continental Shelf (see below).

The Continental Shelf

The shallow continental shelf which dominates the bathymetry of the southern limits of the "Canadian" Beaufort Sea extends from the Alaska border eastward to Cape Bathurst, a distance of about 400 km (Figure 13). The shelf is here defined to be the underwater area characterized by depths less than 100m; this bottom contour generally parallels the coastline. The shelf extends offshore to a distance of about 70 to 150 km. (It is also present off the northern coast of Alaska, but is there less than 100 km in width.) The shelf is extremely shallow and flat in the immediate vicinity of the Mackenzie Delta; the 10 m isobath is attained as far as 35 km offshore. The only significant irregularities in the morphology of the shelf area itself are: furrows resulting from scouring by drifting ice (Section 3.3.5), and protuberances indicating the presence of underwater pingos or pingo-like structures (PLSs). Pingos, which occur sporadically on the shelf, have diameters as great as 300 m at their base and rise to within about 15 m of the sea surface. At these lesser depths, the narrow peaks are breached by expansive forces within the pingos themselves. Another feature of the shelf is the "discontinuous" presence of sea bottom permafrost.

The sole exceptional feature in the shelf area is the Mackenzie Canyon, which extends southward from northeast of Herschel Island toward Mackenzie Bay; this V-shaped canyon has a maximum depth of some 250 m. A few lesser features are also



SCANDINAVIA
Barents Sea
SPITSBERGEN
200 (365)
Norwegian Sea
Greenland Sea
DEPTH CONTOURS IN FATHOMS (METRES)
0 250 500 Miles
GREENLAND
ELLESMERE I.
NORTH POLE
EURASIA BASIN
1000 (1830)
Laptev Sea
LOMONOSOV RIDGE
East Siberian Sea
200(365)
1000(1830)
CANADA BASIN
WRANGEL I.
Chukchi Sea
POINT BARROW
STUDY AREA MAP
BANKS I.
60°
80°
100°
120°
140°
160°
180
40°
20°
0°

Figure 12

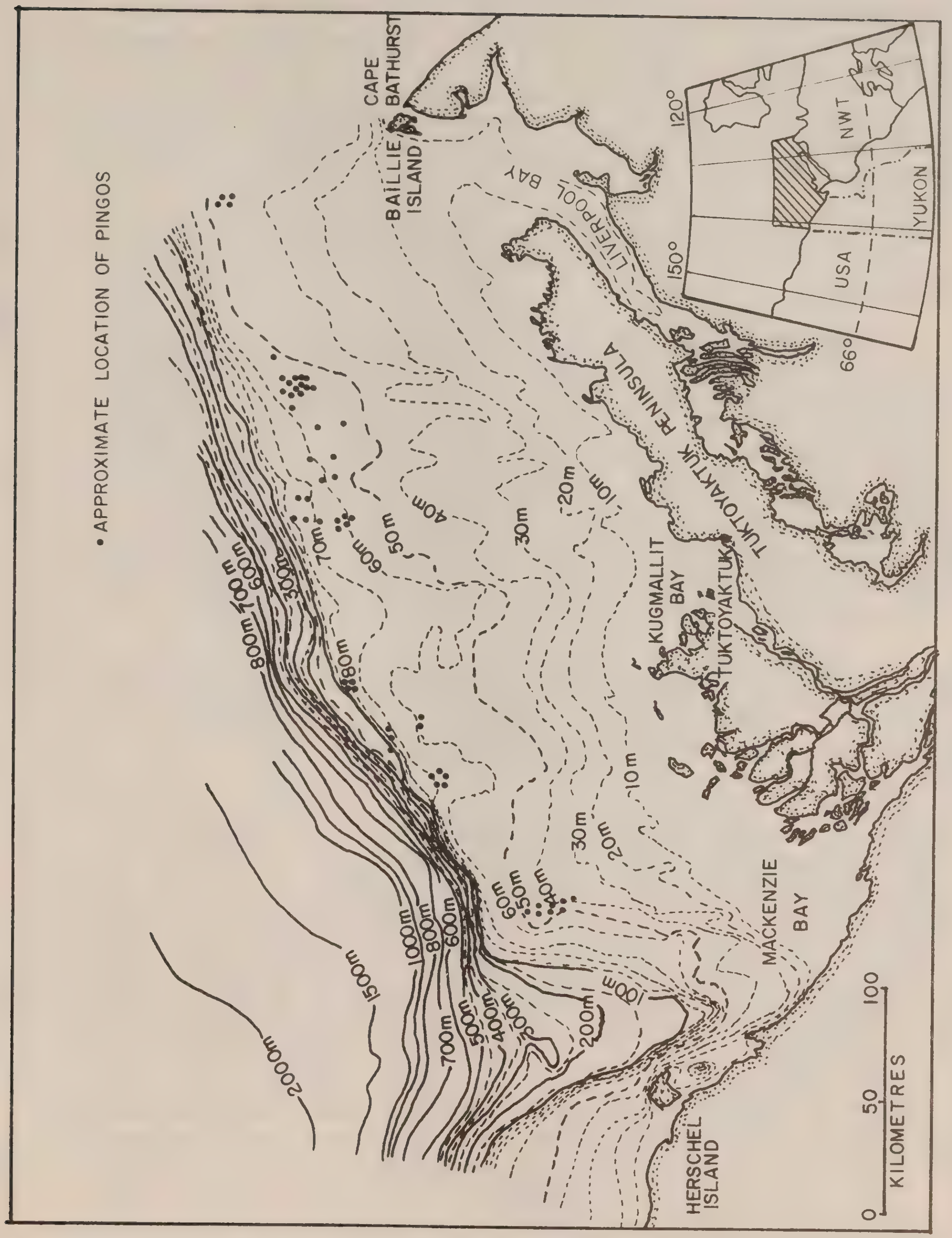

• APPROXIMATE LOCATION OF PINGOS
CAPE BATHURST
BAILLIE ISLAND
LIVERPOOL BAY
TUKTOYAKTUK PENINSULA
KUGMALLIT BAY
TUKTOYAKTUK
MACKENZIE BAY
HERSCHEL ISLAND
NWT
YUKON
USA
120°
150°
66°
0
50
100
KILOMETRES
10m
20m
30m
40m
50m
60m
70m
80m
100m
200m
300m
400m
500m
600m
700m
800m
1000m
1500m
2000m

Figure 13

present; a small deep basin southeast of Herschel Island and to the west of Mackenzie Canyon, and a minor canyon, parallel to Mackenzie Canyon, north of Kugmallit Bay. North of the shelf, the sea bottom slopes downward relatively sharply (the "continental slope") to depths of more than 3,000 m, which are typical of the central portion of the Beaufort Sea. At the western end of Amundsen Gulf, the edge of the shelf is aligned approximately north-south; the bottom drops abruptly to the east, to a depth of approximately 360 m.

3.3.4 Surficial Sediments on the Continental Shelf

Constituents

From the viewpoint of oil drilling operations on the Continental Shelf of the Beaufort Sea, determination of bottom-sediment characteristics (origin, component-particle size, distribution, thickness, etc.) is of great importance. For example, sediment grain-size and thickness are of major concern to installations on the sea floor. Distribution is of importance in resolving the routes and the effects of sedimentary transport, in particular erosion and deposition in the vicinity of artificial drilling islands. The origin and distribution of bottom material could be of significance to the fate of any spilled oil or other pollutants coming into contact with it.

The surficial-sedimentary characteristics of that portion of the Beaufort Sea shelf from about 128^{o}W (Cape Bathurst) to about 141^{o}W (somewhat west of Herschel Island) have been studied during the course of the Beaufort Sea Project.

The only significant source of sediment to the area at present is the outflow from the Mackenzie River. The maximum discharge of Mackenzie River fresh water, and thus of input of suspended minerogenic material, occurs generally during the late spring. The motion of this water subsequent to emergence from the river can be complex (e.g. see Section 4.2); however, the flow tends to the east in the absence of wind. The preference for this direction results from the northern hemispheric effect of the Coriolis force, which tends to move the inflowing fresh water to the right (east).

The textural sediment types, based on constituent grain-size, are present in significant quantities in the surficial deposits on the Shelf (Figure 14): clay, silt and sand.

Clay (here defined to consist of particles of mean grain-size <0.004 mm) is greatest in relative proportion. It predominates off the Mackenzie Delta and over a large portion of the shelf immediately adjacent to the east. An additional small expanse of this fine-grained sediment lies at the extreme northeastern end of the area under discussion, as well as on the Continental Slope adjoining this expanse.

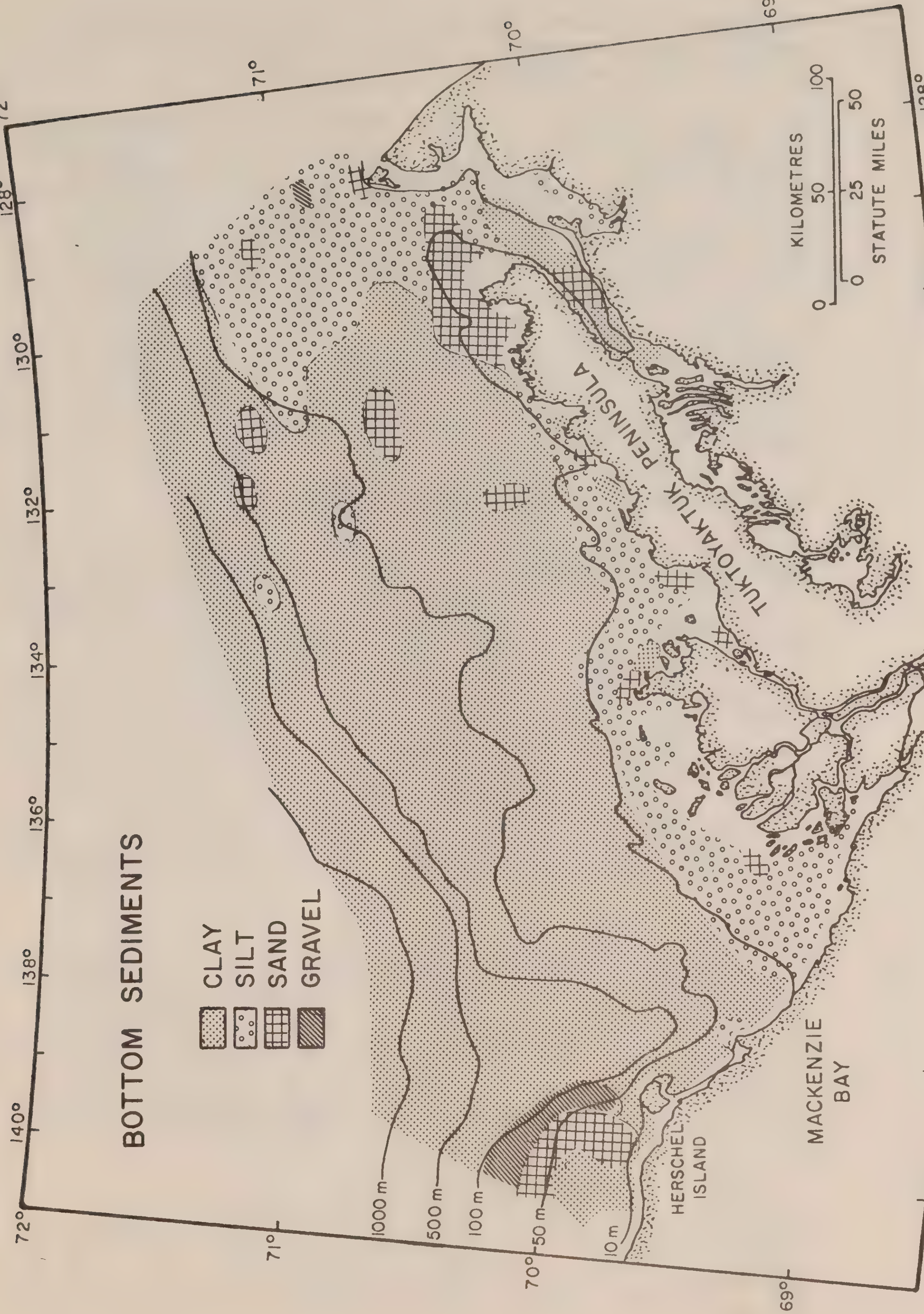

BOTTOM SEDIMENTS
CLAY
SILT
SAND
GRAVEL
TUKTOYAKTUK PENINSULA
MACKENZIE BAY
HERSCHEL ISLAND
KILOMETRES
0
50
100
STATUTE MILES
0
25
50
1000 m
500 m
100 m
50 m
10 m
72°
71°
70°
69°
128°
130°
132°
134°
136°
138°
140°

Figure 14

Sand (mean grain-size 0.062 to 2.0 mm) is the second most abundant type of sediment. It occupies almost the entire area adjacent to the northwestern coast of Herschel Island.

Silt (mean grain-size 0.004 to 0.062 mm) is the next most abundant form. It occupies a narrow transecting zone of the shelf directly seaward of the east-central part of the Tuktoyaktuk Peninsula. This zone appears to have an inter-fingering relationship with both the clay to the west and the sand to the east. Other predominations of silt occur on the extreme eastern part of the shelf adjacent to Amundsen Gulf, and off the Mackenzie Delta just east of Herschel Island.

It may be noted that gravel (mean grain-size 2.0 to 256.0 mm), although present in various localities, does not constitute a significant portion of the sediment except in small areas just to the northwest of Herschel Island and north of Cape Bathurst. It is absent in Mackenzie Canyon.

Relative Proportions of Sediment Types

Clay is present throughout the area, ranging in content from between about 20% to 83% of the surficial sediment (Figure 15). When the distribution of these percentages is displayed by means of 10% contours, the contours are found to be aligned basically parallel to the coast in the western part of the area, but possess a more-or-less transecting pattern, extending across the continental shelf, in the east. In this latter area, the clay content is 30 to 40% less than in the western one; its contours have an interfingering relationship with those representing a greater clay content immediately adjacent on the west. A major area of clay deposition exists in the central portion of the Mackenzie Canyon and on the shelf immediately to the east. The least amount of clay is found northwest of Herschel Island, and in some small areas on the extreme eastern edge of the Canadian shelf.

Silt is the next most abundant textural class (Figure 16) in most samples, ranging in amount from 9 to 68%. As a dominant type areally, it is less widespread than either clay or sand. The greatest concentrations occur in the eastern areas of the shelf, and the least in Mackenzie Canyon and on the central shelf immediately to the east. A pattern similar to that for clay is revealed by the orientation of the 10% isopleths. They lie more or less parallel to the coast in the west and somewhat transect the shelf in the east.

Sand is also present in all samples (Figure 17), but generally in much smaller amounts than is either silt or clay - except on the eastern part of the shelf, in which area it is the dominant constituent. It ranges in amounts from about 0.03% to 65%. The greater concentrations are found in the eastern area of the shelf and on a portion of the shelf west of Herschel Island.

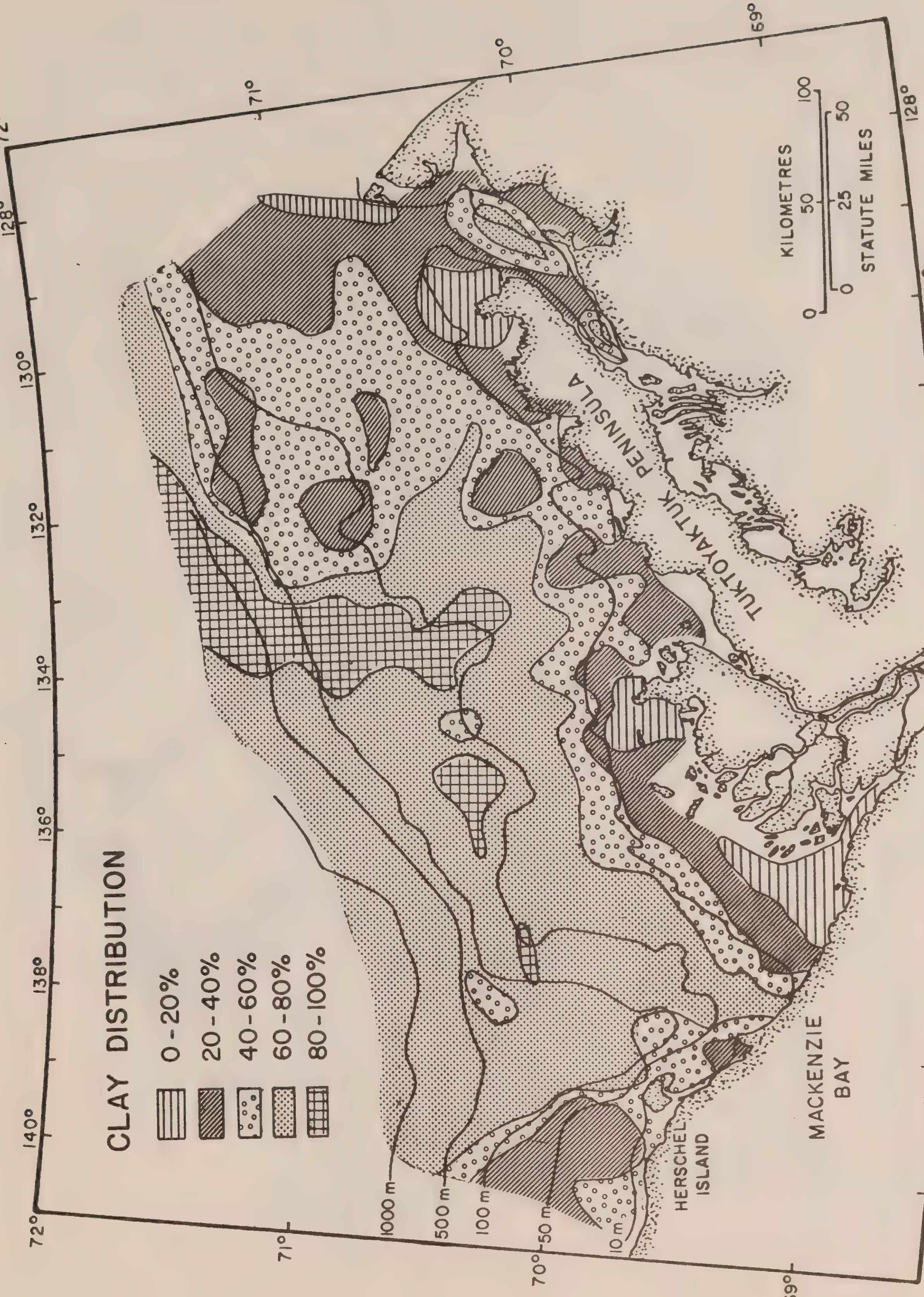

CLAY DISTRIBUTION
0-20%
20-40%
40-60%
60-80%
80-100%
TUKTOYAKTUK PENINSULA
MACKENZIE BAY
HERSCHEL ISLAND
KILOMETRES
0 50 100
STATUTE MILES
0 25 50
1000 m
500 m
100 m
50 m
10 m
72°
71°
70°
69°
128°
130°
132°
134°
136°
138°
140°

Figure 15

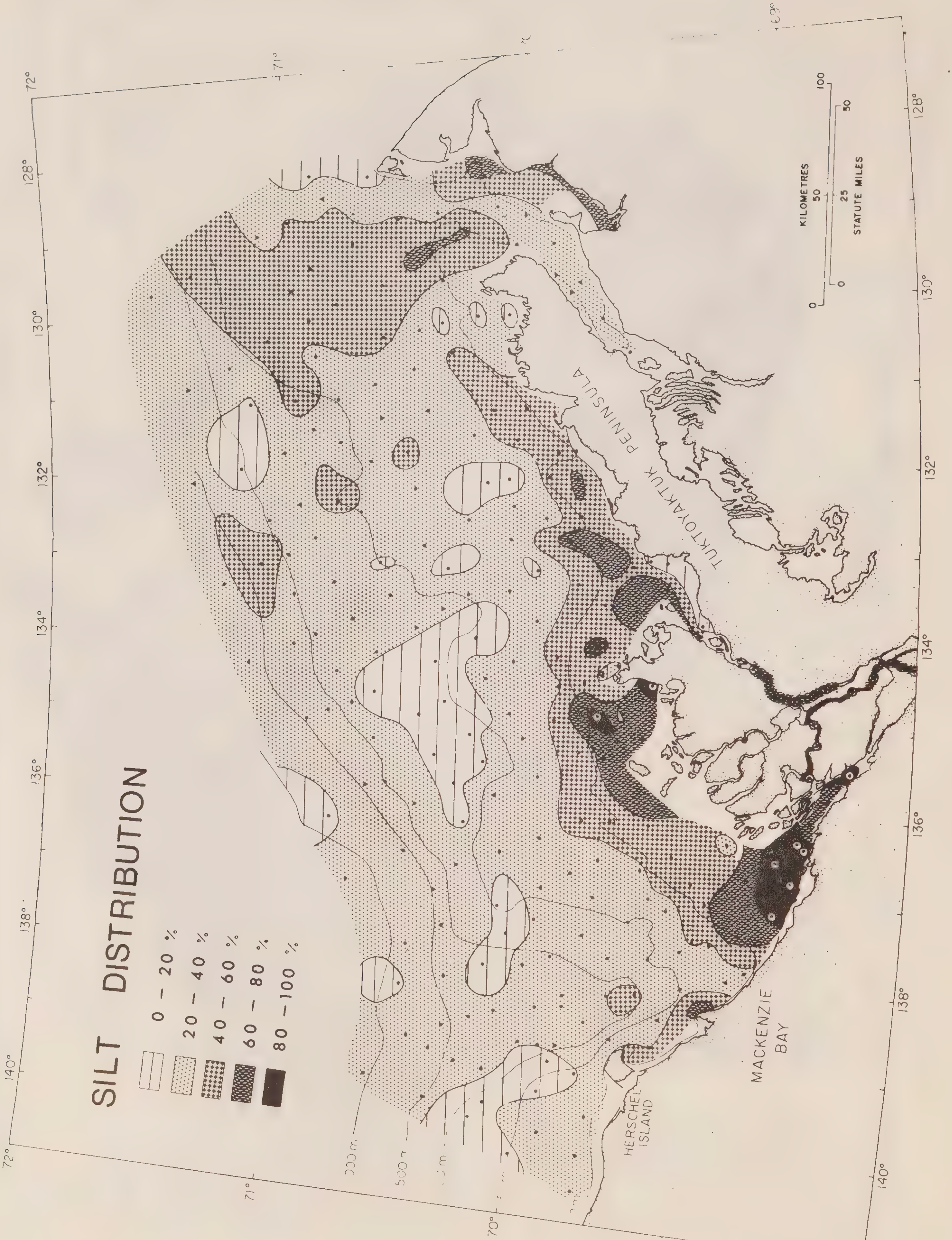

SILT DISTRIBUTION
0 – 20 %
20 – 40 %
40 – 60 %
60 – 80 %
80 –100 %
TUKTOYAKTUK PENINSULA
MACKENZIE BAY
HERSCHEL ISLAND
KILOMETRES
STATUTE MILES

Figure 16

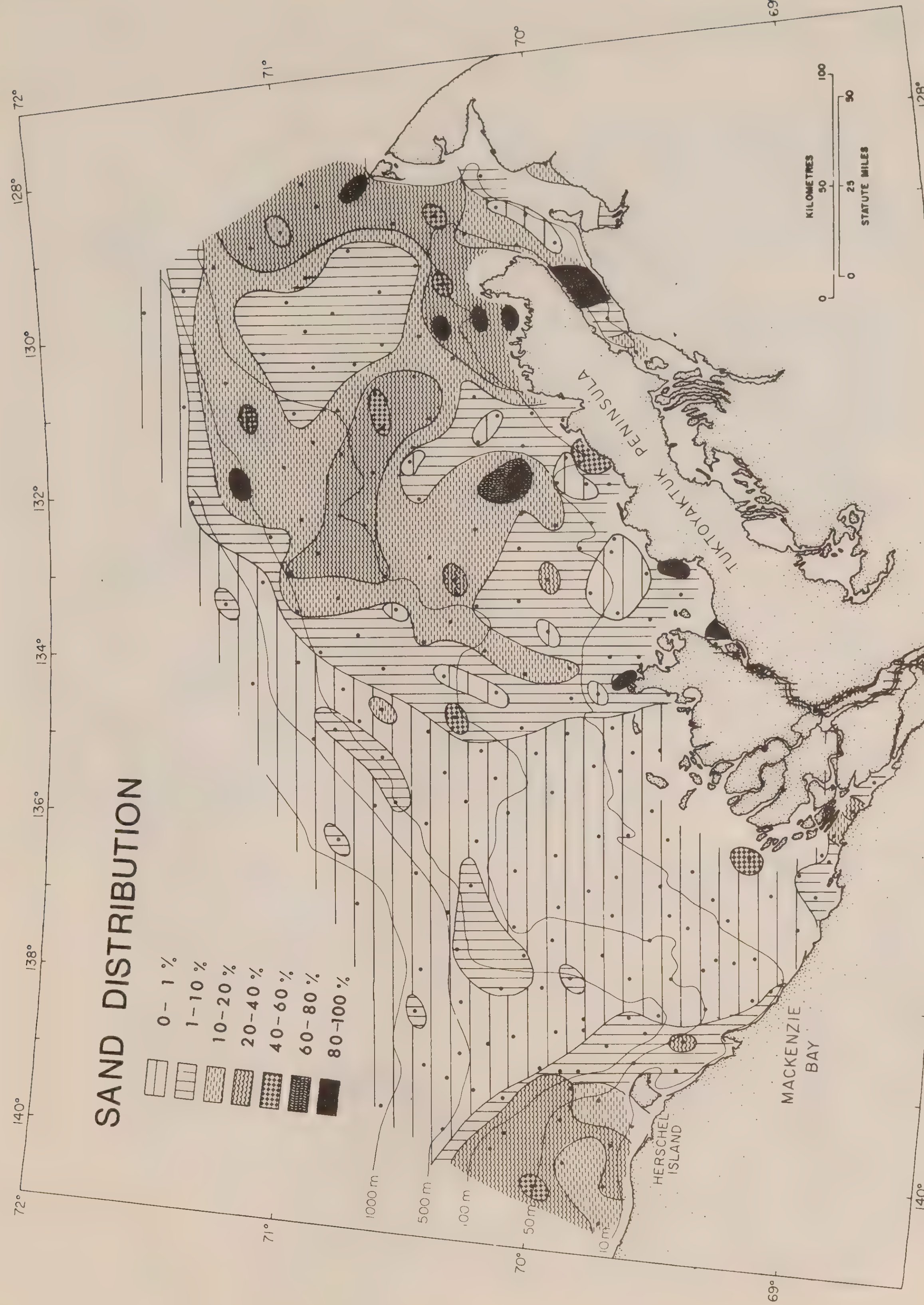

SAND DISTRIBUTION
0- 1 %
1-10 %
10-20 %
20-40 %
40-60 %
60-80 %
80-100 %
TUKTOYAKTUK PENINSULA
MACKENZIE BAY
HERSCHEL ISLAND
KILOMETRES
STATUTE MILES
1000 m
500 m
100 m
50 m
10 m

Figure 17

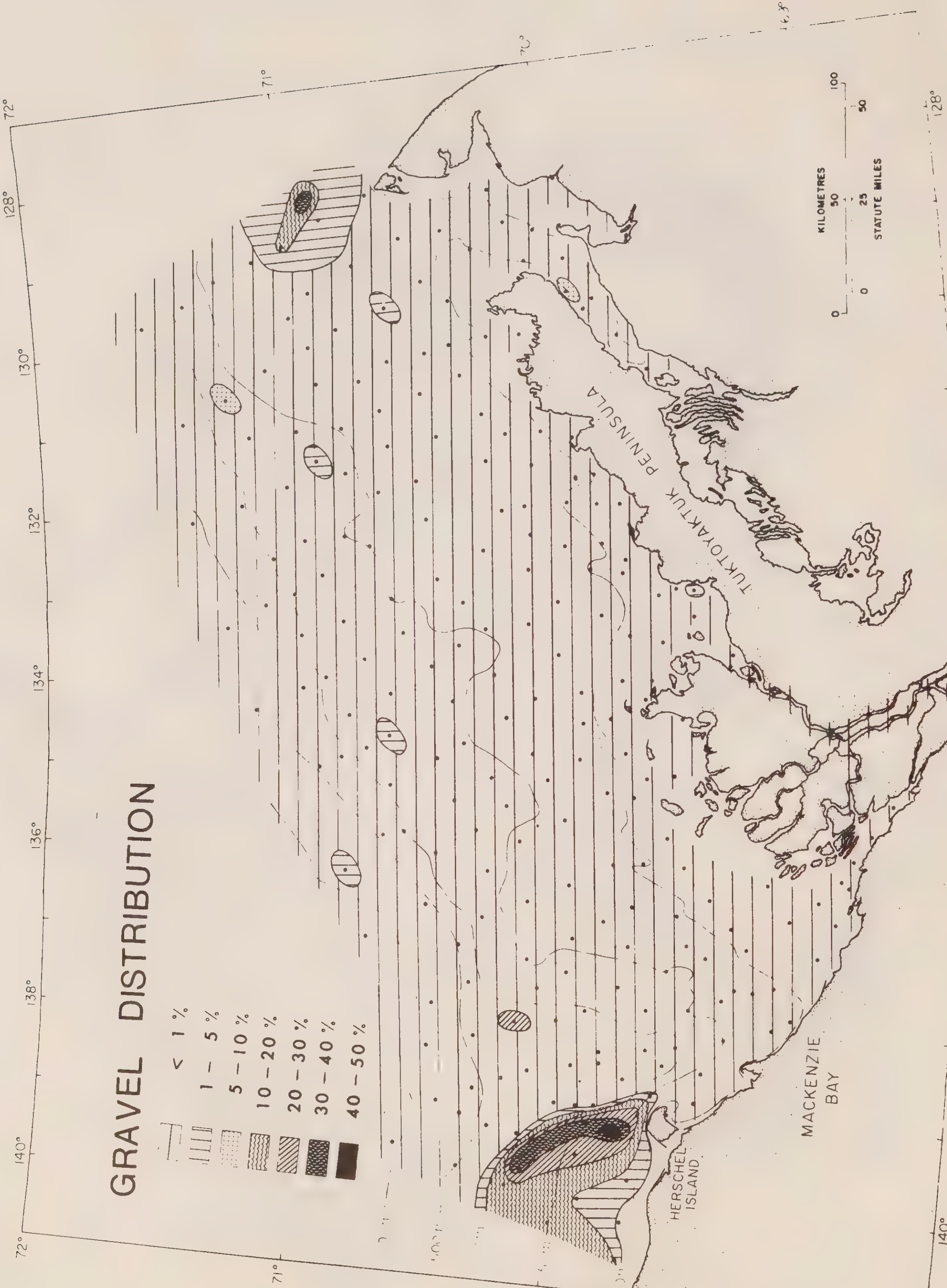

GRAVEL DISTRIBUTION
< 1 %
1 – 5 %
5 – 10 %
10 – 20 %
20 – 30 %
30 – 40 %
40 – 50 %
TUKTOYAKTUK PENINSULA
MACKENZIE BAY
HERSCHEL ISLAND
KILOMETRES
STATUTE MILES
72°
71°
70°
69°
128°
130°
132°
134°
136°
138°
140°

Figure 18

An almost east-west orientation of the 10% isopleths occurs in the central area of the map, but this changes to a pattern that somewhat transects the shelf to the east.

Gravel is the least significant in terms of percentage content (Figure 18). Content ranges from about 0.01% to 38%; about 15% of the approximately 100 samples taken in the study contained no gravel. Except for a few localities in the east and in the general area northwest of Herschel Island, gravel is a very minor constituent of the sediments beneath the Southern Beaufort Sea.

Several representations have been utilized by geologists to provide information upon characteristics of sedimentary deposition and thus, perhaps, upon physical factors affecting them. Two such representations are noted here: sorting, which is a measure of the uniformity of particle size in a sediment, and is usually based on the statistical spread (e.g. standard deviation) of the particle-size frequency curve; the silt/clay ratio, which is believed to possess a sensitive response to dynamic conditions affecting sedimentation, particularly in the absence of coarse sediments.

Sorting in the area, in terms of standard deviation, is displayed in Figure 19. Nowhere in the area was very good or excellent sorting apparent. Areas of fair to good sorting occur in the central portion directly off the Mackenzie Delta, along the entire edge of the continental shelf, and in the coastal zone of Herschel Island. Good sorting generally occurs in areas occupied primarily by clay-sized particles. Poor sorting is characteristic of the sediments occupying all of the eastern half of the shelf and the area northwest of Herschel Island.

The distribution of the silt/clay ratio over the continental shelf is displayed in Figure 20. The larger ratios are believed to reflect conditions of considerable hydrodynamic vigour, and the smaller ratios more quiet conditions. In the Beaufort Sea, the highest ratios (>5.0) occur in Mackenzie Bay and in a small area off the delta. Less than 10 km from the shore the silt/clay ratio decreases markedly, to <1.0; it is smallest (<0.25) between those portions of the 50- and 100-m depth contours off the delta. The ratio of 0.40 has been contoured separately, and outlines the general areas having small values of the silt/clay ratio. It indicates that these areas are sites of least vigorous sedimentation; the ratio also suggests that sediments - as well as discharging from the Mackenzie River and moving easterly - may also move westward, from the eastern end of the continental shelf, toward the area of quiet deposition over and immediately to the west of the Mackenzie Canyon. The isopleths of the ratio generally parallel both the coastline and the isobaths of the continental shelf, except in the eastern part of the Beaufort Sea. There they transect the isobaths.

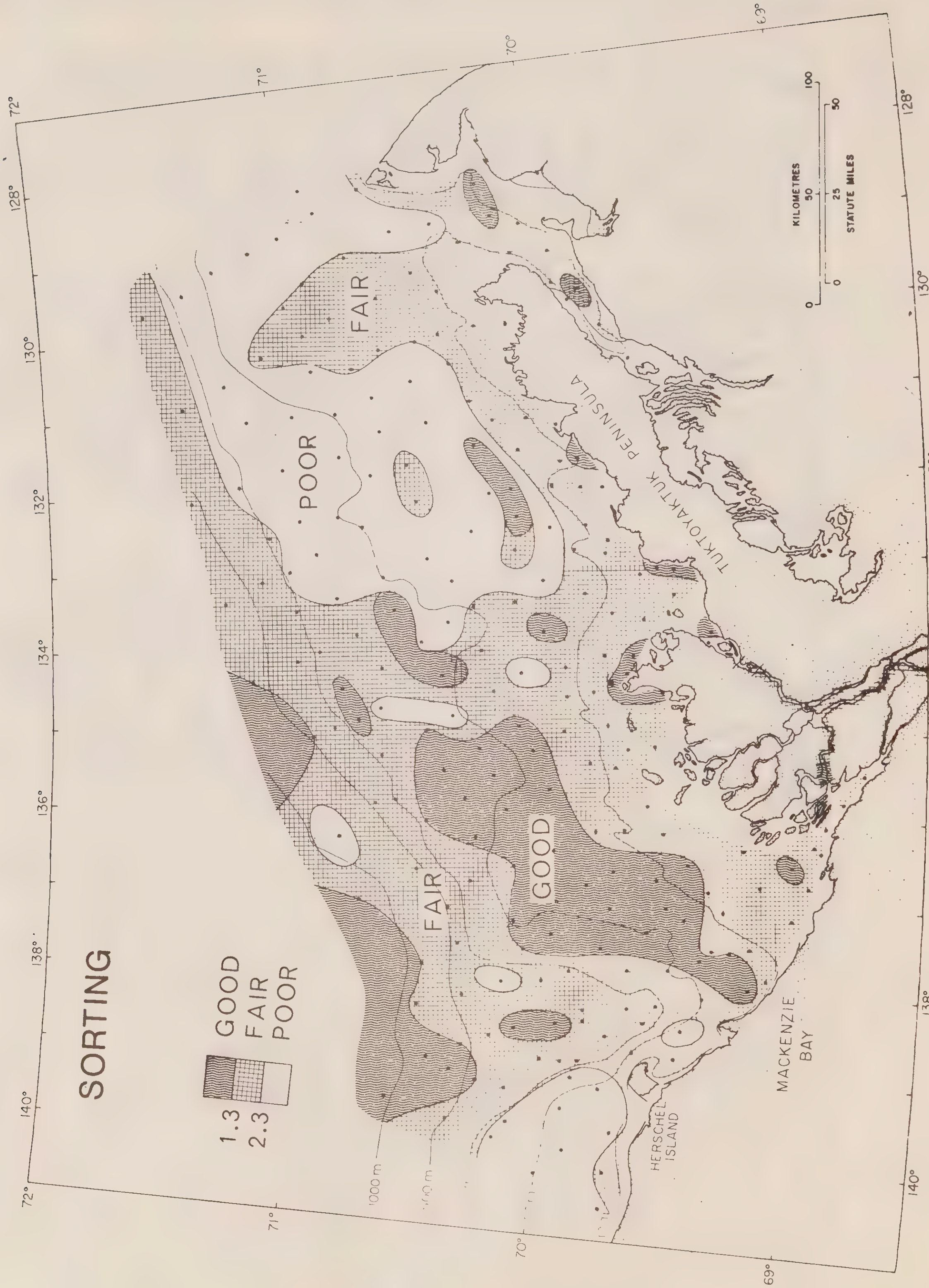

SORTING
GOOD
FAIR
POOR
1.3
2.3
POOR
FAIR
GOOD
FAIR
TUKTOYAKTUK PENINSULA
MACKENZIE BAY
HERSCHEL ISLAND
KILOMETRES
STATUTE MILES
1000 m

Figure 19


SILT/CLAY RATIOS
< .25
.25 – .50
.50 – .75
.75 – 1.00
1.00 – 2.00
2.00 – 5.00
> 5.00
.40
TUKTOYAKTUK PENINSULA
MACKENZIE BAY
HERSCHEL ISLAND
KILOMETRES
STATUTE MILES
0
25
50
100
1000 m
500 m
100 m
50 m
10
72°
71°
70°
69°
128°
130°
132°
134°
136°
138°
140°

Figure 20

Hydrographic Environments

The sediments reported here are suggested generally to fall within three major environments: (1) the intermediate energy zone, (2) the low energy zone, and (3) the very low energy zone. Energy is a measure of the degree of "hydrodynamic vigour". As a rule, the zones decrease in vigour seaward from the Mackenzie Delta and most coasts bordering the Beaufort Sea. The intermediate energy zone lies within Mackenzie and Kugmallit Bays, the adjacent coastal areas and the eastern portion of the continental shelf (Figure 21).

The next environment is one of low energy, lying seaward of the intermediate environment. It extends to the shelf/slope break west of the Mackenzie Canyon, easterly along about the 25 m isobath, west of Mackenzie Bay to a point half way along the Tuktoyaktuk Peninsula, and then northerly across the shelf to the upper part of the continental slope.

Finally, a zone of very low energy occurs seaward beyond the boundaries of the low-energy environment. It extends from almost the head of Mackenzie Bay to Mackenzie Canyon, and across the immediately adjacent shelf to the east. Thus almost the entire central area of the southern Beaufort Sea can be characterized as a zone of very low hydrodynamic vigour.

Sediment Transport

Based on implications from the above-noted factors, a model of sediment transport in the southern Beaufort Sea can be suggested (Figure 22). Longshore drift takes place in both easterly and westerly directions along the coast, as shown by the direction of growth of bars and spits adjacent to headlands and islands. The major contributor of sediments is, however, the Mackenzie River, from which a plume of sediment originates and moves a distance of 55 to 70 km seaward along the axis of the Mackenzie Canyon. This plume veers easterly, since it is influenced almost wholly by the Coriolis force (the no-wind case) and forms a distinctive band about 30 to 40 km wide; it dissipates off the eastern part of Kugmallit Bay. A similar sediment plume emerges from the eastern channel of the Mackenzie Delta, and merges with the plume from the western Mackenzie River in the western part of Kugmallit Bay. Some sediment also moves directly seaward along the Tuktoyaktuk Peninsula, particularly in the eastern part; it appears to be deposited on the edge of the continental shelf.

It is important to note that flocculation of the clay particles occurs within, and on the periphery of, the sediment plume. However, such particles remain fairly small (clay and fine silt, as seen in filtered suspended material), and are carried seaward and deposited with "organic mats". These mats appear to bind the sediment and organic particles and deposit

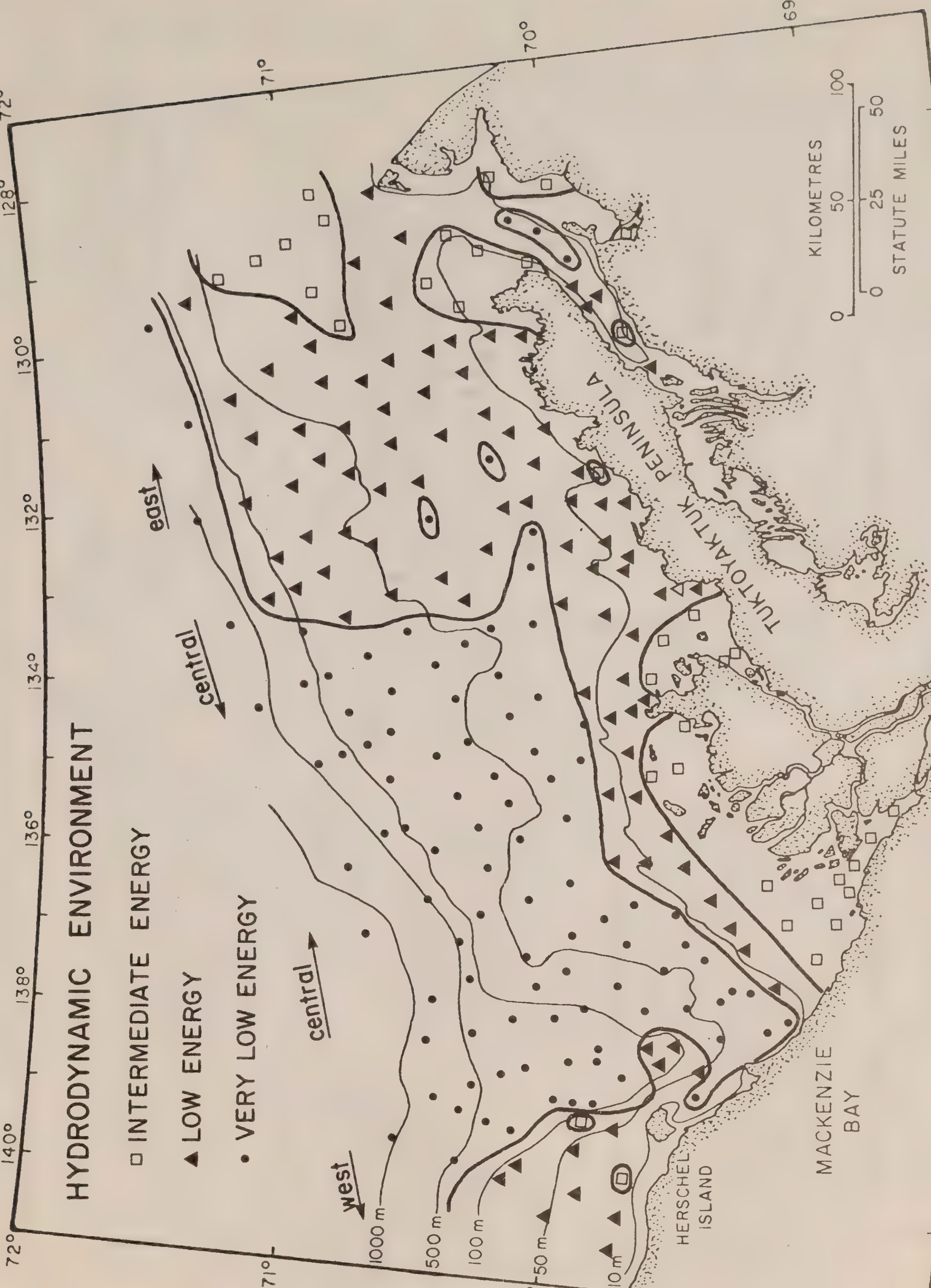

HYDRODYNAMIC ENVIRONMENT
□ INTERMEDIATE ENERGY
▲ LOW ENERGY
• VERY LOW ENERGY
east
central
central
west
1000 m
500 m
100 m
50 m
10 m
HERSCHEL ISLAND
MACKENZIE BAY
TUKTOYAKTUK PENINSULA
KILOMETRES
0 50 100
STATUTE MILES
0 25 50
72°
71°
70°
69°
128°
130°
132°
134°
136°
138°
140°

Figure 21

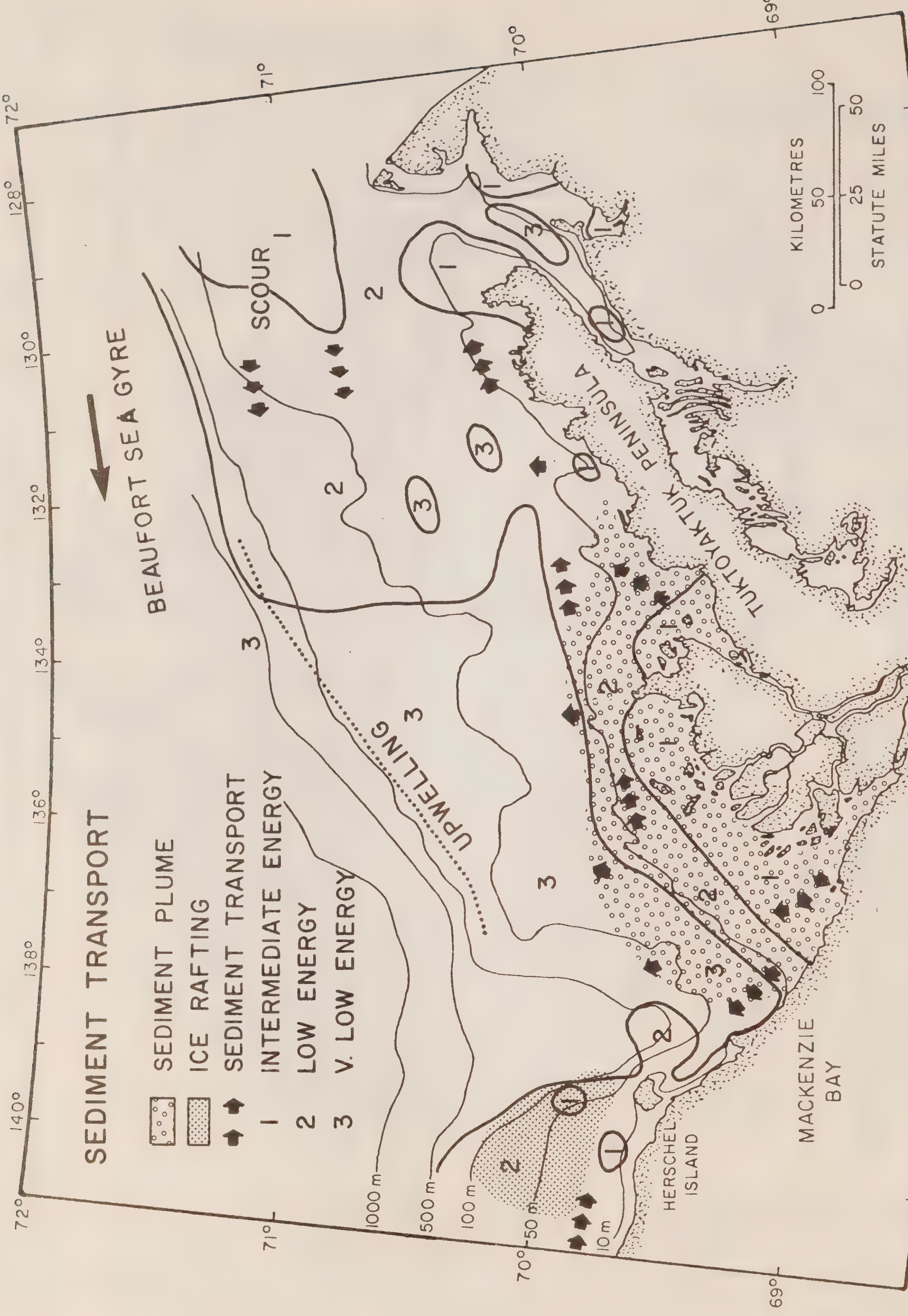

SEDIMENT TRANSPORT
SEDIMENT PLUME
ICE RAFTING
SEDIMENT TRANSPORT
1 INTERMEDIATE ENERGY
2 LOW ENERGY
3 V. LOW ENERGY
BEAUFORT SEA GYRE
UPWELLING
SCOUR
TUKTOYAKTUK PENINSULA
MACKENZIE BAY
HERSCHEL ISLAND
1000 m
500 m
100 m
50 m
10 m
KILOMETRES
0 50 100
STATUTE MILES
0 25 50
72°
71°
70°
69°
140°
138°
136°
134°
132°
130°
128°

Figure 22

them in quieter waters.

During the winter the Beaufort Sea Gyre (Section 4.2.1) can migrate southward, so that a westerly current may then be available to transport fine material (silt and clay) to the west. A possible "race-track" model for sediment transport can be envisioned, in which sediments continually move easterly and veer northerly off Liverpool Bay, and continue to veer to the left so that the direction of movement is finally westerly. However, this model is unlikely to be true as certain shear forces associated with the movement of the Beaufort Gyre southward tend to produce discontinuities along the boundary separating easterly and westerly moving sediments. Upwelling observed along the western continental shelf/slope break may introduce sediments to the outer shelf; this may occur east of Mackenzie Canyon as well.

An ice-rafted deposit occurs north of Herschel Island; this is distinct from most other occurrences of gravel on other parts of the shelf. The origin is suggested by the presence of poor sorting, a low content of fine sediment and the fact that the sediments occur in a low-energy environment.

The model of sediment transport shown in Figure 22 is in general accordance with the observed movement of sediments from environments of higher hydrodynamic energy to those of lower vigour. Concomitant with this movement, the sediments decrease in size in the direction of sediment transport.

Summary

Except for the area northwest of Herschel Island, which is thought to be receiving ice-sifted deposits, sediments on the Beaufort Sea shelf are mainly fine-grained; they consist predominantly of clay and silt in the western and central areas, and of somewhat coarser types in the eastern part. In the delta area and immediately offshore, this dispersal pattern is partly a result of the fine-grained sediment discharged from the Mackenzie River. Over the eastern portion of the shelf, the pattern is due partly to the sedimentation of fine particles over a relict surficial sand and partly to the possibility that this sand may be intermittently eroded by westward-moving bottom current. Thus the western shelf appears to serve alternately as a depositional and erosional site.

Finally, it may be noted that there is some evidence that geologically-recent submergence of the sea floor has been a dominant factor in creating the site of quiet deposition suggested to occur near the front of the Mackenzie Delta.

3.3.5 Ice Cover in the Beaufort Sea

Ice is a major feature of the Beaufort Sea area, as it is throughout the arctic generally. Both salt and freshwater varieties can be present. The former type originates by the freezing of seawater; it is common both to the open sea itself and to adjacent coastal waters, and can be permanent or seasonal according to location. The latter form can occur in the areas immediately adjacent to the Beaufort Sea throughout the year. It is seasonally present in rivers and lakes throughout the Mackenzie Delta and more inland areas. It also occurs in the Beaufort Sea itself in the form of ice islands (see below); such islands, however, represent a minor constituent of the total amount of ice there. With the exception of these islands, freshwater ice will not be discussed further in this report. Therefore, unless noted otherwise, the term "ice" shall henceforth in this section refer to sea ice.

The various characteristics of ice (e.g., thickness, extent, strength, lifting force, bearing capacity, degree of motion, growth, breakup, freeze-up and jamming) are of vital concern to most aspects of transportation, construction and operation of equipment in the Arctic regions. The design, construction and maintenance of oil rigs, piers, caissons, dams and pilings; the choice, and the successful operation of, transportation (in the sea, land or air mode); the degree of retention of spilled oil or of other pollutants within the pack ice, as well as the nature of their release; the integrity of shorefast structures; are but a few of the factors that can be vitally affected. Ice can also play a significant role in both the transport and the fate of any pollutants discharged into arctic waters. Its presence can also significantly affect the degree to which oil spill countermeasures can be successfully applied.

Types of Ice

The quantities and kinds of ice are controlled by the characteristic of origin, formation, growth, deformation, draft, disintegration and decay.

Sea ice in the Beaufort Sea is primarily in the form of floes. Individual floes are relatively flat pieces of ice generally about 20 m or more in extent. A large floe may be 50 - 2000 m in largest lateral dimension; the greatest recorded has been several tens of kilometres in extent.

Pack ice (Figure 23) is used to signify, in a broad sense, any accumulation of sea ice other than "shorefast" or "fast" ice (page 44). Here it refers specifically to a broken random mixture of floes of various sizes and ages, interspersed at various times with leads and polynyas where ice has eroded and parted; hummocks, as well as lines of pressure ridges, are also primary characteristics. A lead is defined to be a long,


Main Polar Pack
Cape Bathurst
Cape Dalhousie
Loose Polar Pack

Figure 23

narrow, jagged crack, in the ice, which is navigable by surface vessels. A polynya is a non-linear-shaped expanse of open water completely enclosed by ice. Hummocks are hillocks of broken ice which have been forced upward by very strong lateral pressures. Pressure ridges are lines of hummocks or walls of broken ice forced upward by pressure. By definition, the polar pack represents ice cover greater than about seven-tenths (7/10). The pack is composed primarily of old ice, i.e., that which has survived for two winters or more. This old ice is often considered as being composed of second-year ice and of all other (multi-year) ice.

The ridges and hummocks often interrupt broad, relatively flat expanses of pack ice. They can occasionally rise to 12 m or more above the surrounding level. In general, the thickness of the pack ice increases from south to north in the Beaufort Sea, the relatively flat expanses ranging from 2 to 3 m in the southern part to probably about 3 to 4 m in the central part. Thus, when compared to the depths characterizing the open Beaufort Sea, the pack ice constitutes merely a thin film on the sea surface. However, the consequences of its presence to human activity are everywhere profound, especially, as previously noted, in the coastal area of present concern.

In areas in which individual ice floes are concentrated and subjected to strong lateral pressures, rafting can occur (Figure 24a,b). This process, in which one floe overrides another, can produce large thick masses which resemble ice islands (see below) in their various dimensions, although generally somewhat smaller. These masses may therefore at times be confused with such islands.

Icebergs are massive fragments of ice of land origin which have attained heights of more than 5 m above sea level and have broken away (calved) from a glacier. They can be characterized by different types of relief, but the largest individual pieces within the Arctic Ocean in general are the tabular bergs known as ice islands (Figure 24c). The source of such islands is believed to be an ice shelf, or series of shelves, off the northern coast of Ellesmere Island in the Canadian Arctic Archipelago. These islands can be as much as 700 km^2 or more in area - although most are considerably smaller. The thicknesses range from 10 to 60 m. Their size and lifespan make some of them valuable as sites for research camps; among other quantities their motion is studied as a clue to the circulation of the shallow layers in which they reside.

Shorefast ice is sea ice which forms and remains horizontally fixed along a coast. This is primarily formed in the Beaufort Sea by freezing of sea water, or perhaps by freezing of shallow pack ice of any age, to the shore. It is seasonally recurring, breaking up in summer.

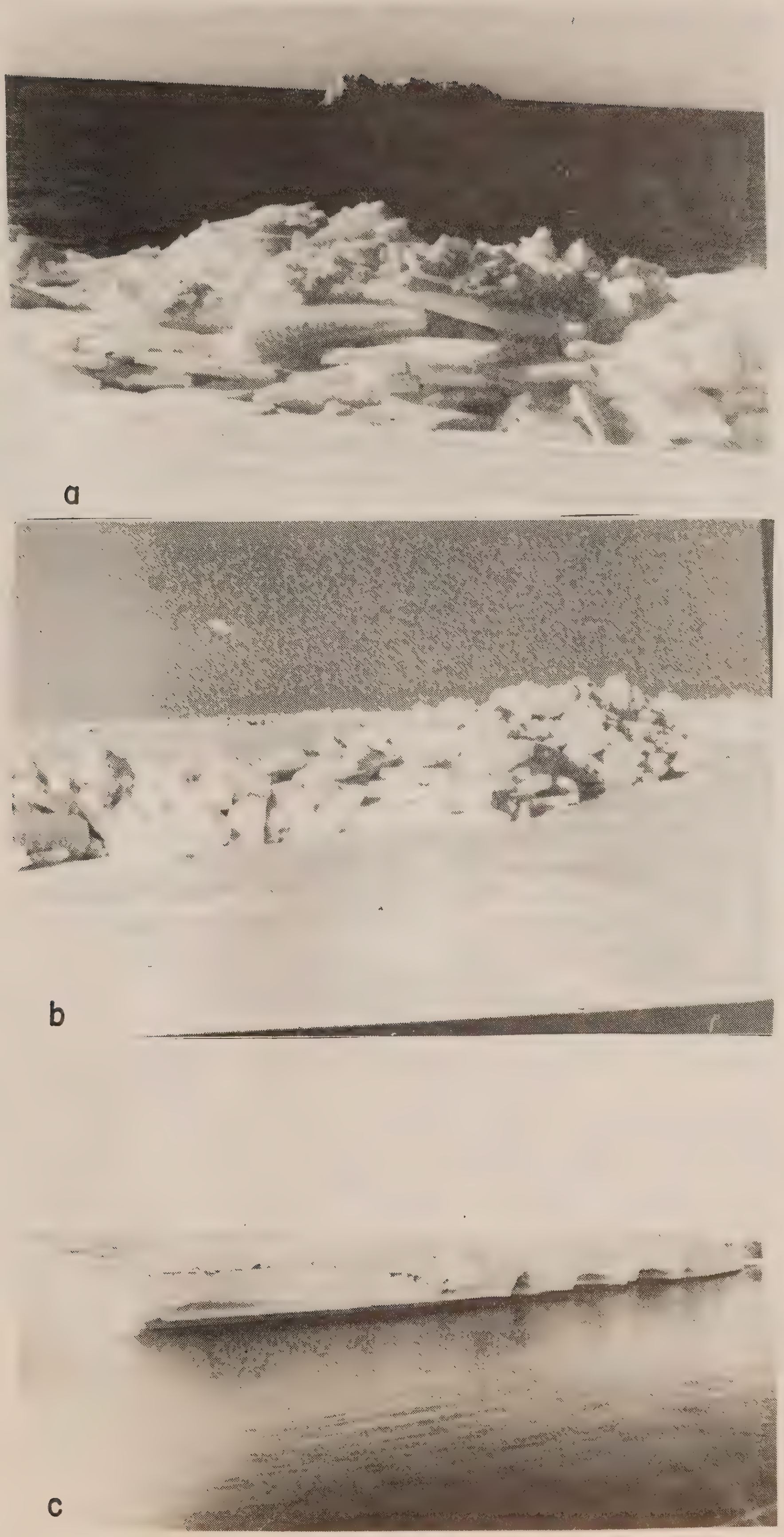


Figure 24

Ice Movement

The horizontal motion of the non-shorefast ice is one of its most important characteristics. The motion at any time is determined by several factors, such as the currents (wind-driven, tidal and residual) on that portion of the ice below the sea surface, the wind effect on the portion above the sea surface (sail effect), and the resistance against motion offered by the ice itself. Two aspects of this resistance bear consideration: the totality of the frictional stresses associated with the concentration of "packing" of the ice, and that associated with the draft of the ice.

In the open Beaufort Sea all non-fast ice will tend to undergo the slow, generally-clockwise persistent motion associated with the Beaufort Sea Gyre (page 103), which is generally characterized by speeds averaging about 2-4 cm/sec (1.7-3.4 km /day). However, speeds several times larger can occur for short periods.

Superimposed on this motion will be the drift associated with the local winds. The rate of this drift is apparently about 2-3% of the (near) surface wind speed, thus being, for a wind of 10m/sec, of the order of 10 times the speeds associated with the Beaufort Gyre. It will be affected by the area and roughness of the ice surface presented to the wind and by the concentration of the ice (e.g., pack ice, or a number of distinctly-separate floes or ice islands).

First-year ice, being relatively thin, will tend to move in the direction of the prevailing wind. Pack ice, and to a far greater degree floes and ice islands, have a greater draft, as well as a greater above-surface height, than does first-year ice. However, the draft is generally much more important than is the sail effect, and thus the ice tends to move more with the direction and speed of the depth-integrated current rather than with those associated with the wind or with the near-surface current. If a strong wind blows steadily for several hours, it would appear that the floes or islands should be acted upon even more forcefully, both the sail effect and the surface-water drift contributing to motion in, or near to, the wind direction. The angle of deflection increases, and the speed decreases, with an increase in ice thickness. Because of the inertia associated with the relatively large mass of the pack ice, or even that of individual floes and islands, the ice may continue to move under wind influence for some time after the wind stops or changes direction.

In summary, ice will move with the greatest speeds when the wind is strong and the ice cover is relatively light. If the cover becomes heavier, internal stresses and friction become more significant, and the pack ice as a whole tends to move more slowly than do the individual floes or islands.

As previously noted, the day-to-day variations in ice drift can be great in both speed and direction, and arise from fluctuations in wind and ocean-current speeds and in frictional resistance of the pack ice. However, the general westward-trending motion imposed by the Beaufort Gyre dominates the overall net movement of ice, the effect increasing with distance offshore.

Currents in inshore waters have greater prevailing values (as well as more marked spatial and temporal variability) than do those in open-sea areas. These enhanced currents, due in general to combinations of the effects of fresh water runoff, wind and tide (Section 4.2.2) can contribute significantly to the breakup of shorefast ice. Vertical motions in this ice can be induced by changes in sea level.

Ice Conditions in Winter

During November and December, the shorefast ice grows in thickness and increases its area in a series of seaward steps, dependent partly upon the strength and frequency of onshore winds. These winds consolidate loose floes at the edge of the fast ice; these floes then remain in place during offshore drifts. By late winter this ice is present along the entire Beaufort Sea mainland coast (Figure 25); it has grown annually from open water, and its seaward limit generally remains remarkably close to the location of the 30-m bottom contour. It covers the bays and lagoons along the coast. It narrows to only a few km in width in the Barter Island-Herschel Island area, then broadens to a width of about 18 to 55 km offshore of Mackenzie Bay. It extends eastward to Cape Bathurst. A significant amount of such ice can also form on the west coast of Banks Island, particularly in the northern half where offshore islands assist in its formation.

The thickness of first-year ice is usually 1.0 to 1.2 m in January, increasing to about 1.5 m in late March and to about 1.8 m in May (from Point Barrow to Cape Parry). On the western coast of Banks Island it attains a thickness of about 1.8 to 2.0 m by May.

The northern portion of the sea is filled with essentially multi-year ice moving, in a clockwise manner, past the shores of Banks Island and across the Mackenzie River mouth and farther to the west. During this motion, the multi-year ice is broken, refrozen, compressed and extended into a wide variety of shapes ranging from rubble fields to pressure ridges up to 12 m in height. Even in winter, thermal and wind stresses may cause fracturing and the formation of open leads in the pack ice. However, these soon freeze over, providing sources of first-year ice among the predominant older ice. The nearshore boundary of the polar pack in winter usually lies over about the 500-m depth contour, near the seaward edge of the continental shelf.

Figure 25

Between this moving polar pack and the first-year fast ice attached to the shore is the transitional or shear zone (Figure 26), the latter term being applied because of the relative movement (shear) generally occurring between the two major ice masses. In a normal year, this zone usually extends to about 100 to 200 km seaward of the fast ice on the continental coast. (However, the pack is generally only 0 - 100 km seaward of Banks Island.) Even in mid-winter there is some open water in this zone. A more or less permanent boundary lead is present just north of the shorefast ice. Much of the open water is, however, temporary and variable; for the main part, the zone is filled with fragments of ice broken off from either side. The term "seasonal pack" has been used to describe this conglomeration of ice, since it often resembles the polar pack. These floes are in a continual state of movement and collision; leads open and close, ridges are formed and the resulting large floes are rebroken at a different angle. New ridges are interspersed with old ones existing in the original pack mass and an observer flying over the area sees a chaotic jumble of cross-hatching of ridges and leads; floe sizes range from very small up to several km in linear extent. As the shorefast ice is neared, the zone is featured both by an increasing number of pressure ridges and by more first-year ice.

It may be noted that, because of ridging and hummocking, the older floes are much more variable in thickness than is the first-year ice, averaging 3.5 m. The ridges themselves average about 3 m in height. Ridge frequency of about 10 per kilometre is indicated for pack ice - with somewhat reduced frequencies in the area adjacent to Amundsen Gulf, and higher values along the continental coast.

Spring Breakup

Although as already noted the winter-ice state in the Beaufort Sea exhibits little yearly variation, both the process of spring breakup and the resulting extent of open water area show considerable year-to-year variability. The severity of the previous winter conditions and the coastal wind régimes during late spring and early summer are perhaps the primary determining factors.

In spring, east and southeast winds can become common in the Beaufort Sea. The beginning of breakup is first evident in March with the widening of flaw leads, generally west of Banks Island, under the thrust of these winds. Simultaneously the westward movement associated with the Beaufort Gyre produces another long flaw lead at the mouth of the Amundsen Gulf, either at the seaward edge of the landfast ice or further offshore - within the transition zone. Additional radial leads, perpendicular to the coast, also open in the zone and form part of an extensive interconnecting lead network. The whole system eventually forms a large polynya, which soon becomes a major centre

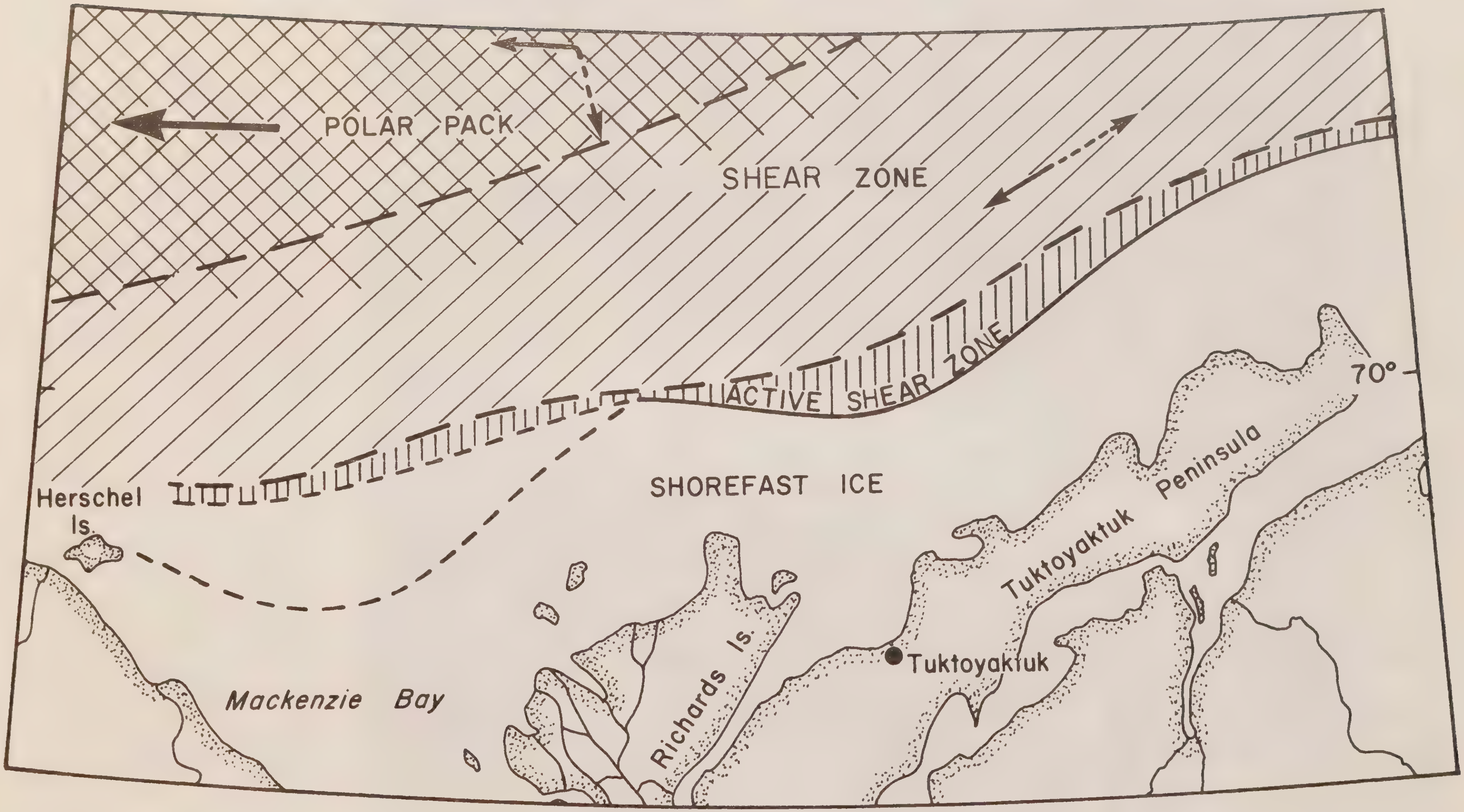

POLAR PACK
SHEAR ZONE
ACTIVE SHEAR ZONE
SHOREFAST ICE
Herschel Is.
70°
Tuktoyaktuk Peninsula
Tuktoyaktuk
Richards Is.
Mackenzie Bay

Figure 26

of subsequent disintegration of ice (Figure 27).

In general, breakup proceeds from south to north and starts about one week after the mean temperature exceeds $0^{o}C$. It is caused by the slowly rising air temperatures, by melting of the snow cover, and by warm water moving northward.

Actual melting of the ice itself begins about early June, as shown in Figure 28. Extensive fresh water ponding (dark areas) will occur on the large floes and on the shorefast ice; some water may drain off through cracks in the ice. There is a brief period during which snow and the upper surface of the ice are melting and the bottom surface of the ice is simultaneously growing.

A summary of the general features of the breakup process can be given:

1. Initially the snow-melt runoff forms pools of fresh water on top of the shore ice.

2. With slowly rising temperatures, there is a further melting and the development of a shore lead.

3. The widening of this lead is assisted by tidal action, vertical motions in the water, coastal currents and winds; eventually the ice may break up to a considerable distance from shore.

Locally, the breakup process may be assisted by other factors. For example:

a) The Beaufort Sea Gyre west of Cape Parry causes a new drift of ice away from the sector between Sachs Harbour and Tuktoyaktuk;

b) The tidal exchange between Amundsen Gulf and the central Beaufort Sea, coupled with vertical motions in the water and coastal currents, helps to break up the ice;

c) The Banks Island polynya weakens the ice, causing a disintegration center which allows the penetration of solar energy into the water, furthering the breakup process and accelerating melting;

d) At the mouths of rivers flowing into the Arctic, the relatively warm river water hastens breakup nearby.

The first breakup and clearing of ice occurs generally in late June in the shallow Mackenzie and Kugmallit Bays and progresses along the coast in either direction. However, this is a special circumstance because of the effect of the relatively

Figure 27

Figure 28

warm water associated with the Mackenzie River freshet, and the extensions are very slow at first.

Meanwhile, the Cape Bathurst polynya expands slowly in all directions; however, the associated breakup does not become significant until late July. The Beaufort Sea Gyre west of Cape Kellett will generally cause a net drift of ice away from the Cape Bathurst area. While this polynya is expanding and helping to clear the southeastern Beaufort Sea, a lead also develops along the Alaska coast from Bering Strait and Cape Lisburne towards Cape Barrow. This is also aided by consistent southeast winds.

The mean dates that some coastal areas in the southeastern Beaufort Sea are clear of ice are displayed in Figure 29. In saltwater areas in the vicinity of Mackenzie Bay, clearing occurs near the end of June. By mid-July, coastal areas contiguous to Amundsen Gulf are free of ice. Except in the vicinity of the Cape Bathurst polynya, clearing elsewhere along the Arctic Coast is usually delayed until late July. The average amount of elapsed time from the mean date of first deterioration of ice to the mean date of open water ranges from 30 to 50 days along the coast.

Ice Conditions in Summer

During the summer the polar pack consists of multi-year floe ice, pressure ridges, rotted first-year ice, leads and polynyas.

By early August of an average year, continued melting and breakup of the floes permits reasonable navigation conditions, for ice strengthened ships, along the coast from Point Barrow to Barter Island and into the Cape Bathurst polynya. At this time this polynya usually extends from Herschel Island to Cape Parry and beyond. Throughout the remainder of August, melting gradually moves the ice edge landward, allowing easy navigation until freeze-up begins. In an ordinary year, the pack will retreat to 100 to 200 km from the Alaska coast, and 200 to 1000 km from the Canadian mainland. It usually remains close (0 - 100 km) to Banks Island from Cape Kellett to Cape Prince Alfred.

Year-to-year variations in summer ice-cover conditions can be large. Should southerly or easterly winds prevail in the open Beaufort Sea, the main pack ice can retreat well offshore (as far as 73^{o} to 74^{o}N) in August and September. The open water season can commence as early as late June and end as late as the latter part of October. These conditions represent a "good ice-year".

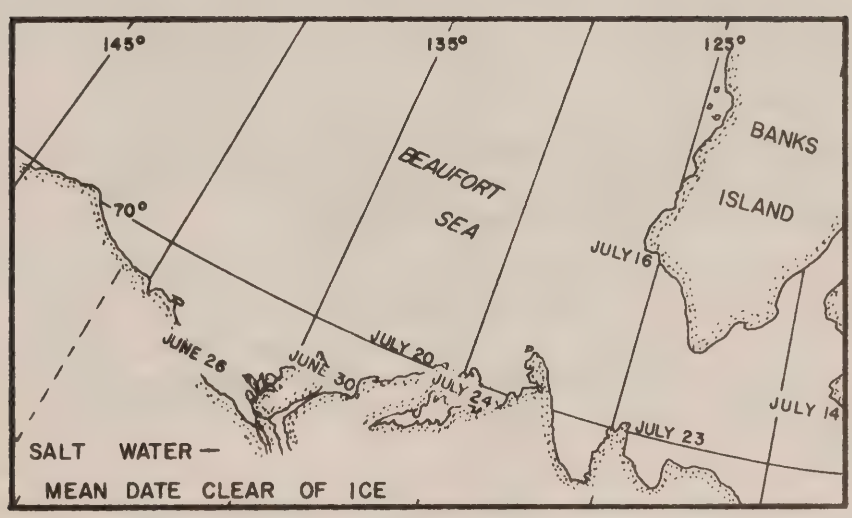

145°
135°
125°
BANKS
ISLAND
BEAUFORT
SEA
70°
JULY 16
JUNE 26
JUNE 30
JULY 20
JULY 24
JULY 23
JULY 14
SALT WATER —
MEAN DATE CLEAR OF ICE

Figure 29

On the other hand, should northerly winds prevail, the pack ice will then feed continually into the nearshore areas. The coastal channel may not open until well into August and may be closed again by freeze-up early in September. Such conditions signify a "poor ice-year". The frequency and strength of northerly storms appear to be determining factors in controlling ice conditions in summer.

The extremes that can occur in sea-ice conditions during the months May through October are depicted in Figure 30a to 30c. The envelopes enclose areas within which either open water or $\leq$7/10 ice cover occurs; the envelopes associated with the latter quantity are considered as denoting the limit of the polar pack. The two maps for each month show the most and least ice cover. It is obvious from these illustrations that terms such as "average ice-year" and "average extent" of pack ice have little significance or relevance to oil-drilling operations in the Beaufort Sea.

Autumn Freeze-up

Freeze-up generally commences in late September or early October. Sea-ice formation can be considered to proceed approximately by the following main steps:

a) When there is sufficient cooling of the water surface, convection currents are initiated due to the increased density of the water. As the temperature falls, these gradually extend to greater and greater depths. When the freezing point is reached, crystals of pure ice are formed.

b) As freezing continues, the ice crystals grow into a matrix. During this process the temperature of the ice is lowered, part of the trapped sea water freezes, and the size of the brine cells is reduced. Extreme cooling can result in salt crystals within the ice.

c) Some sea water may also be mechanically trapped during the formation process; the amount varies directly with the rate of freezing, and as a result this phenomenon occurs mainly in the early stages of formation.

d) Increasing ice thickness and preferential crystal growth result in elongated vertical crystals in the lower levels of the ice layer, with small brine cells occurring between them.

e) Variations in temperature during the winter, as well as the normal temperature gradient in the air, result in a downward migration of the brine cells and a gradual freshening of the ice as it ages.

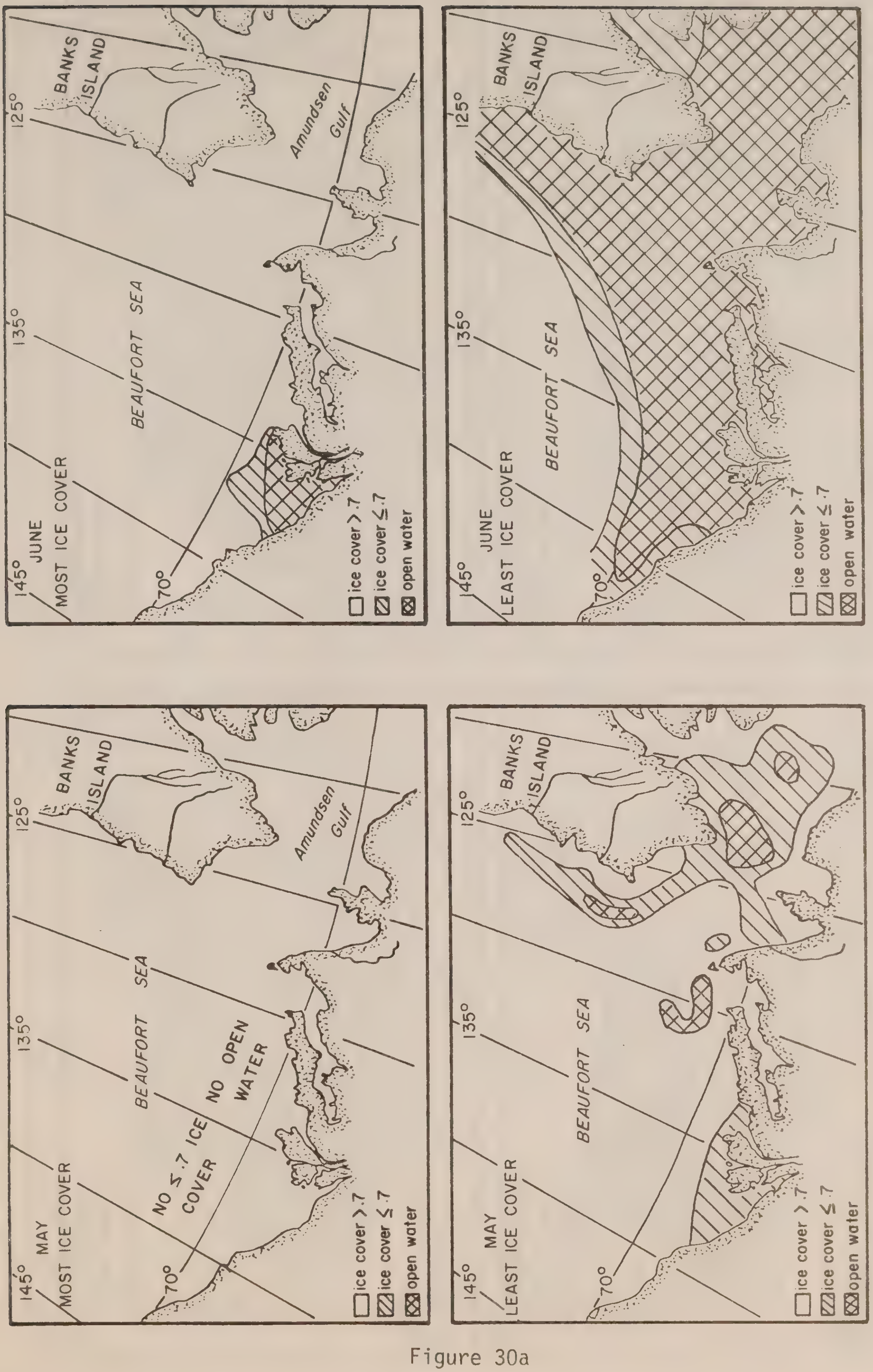

JUNE
MOST ICE COVER
JUNE
LEAST ICE COVER
MAY
MOST ICE COVER
MAY
LEAST ICE COVER
BANKS ISLAND
Amundsen Gulf
BEAUFORT SEA
NO ≤ .7 ICE COVER
NO OPEN WATER
145°
135°
125°
70°
ice cover >.7
ice cover ≤.7
open water

Figure 30a

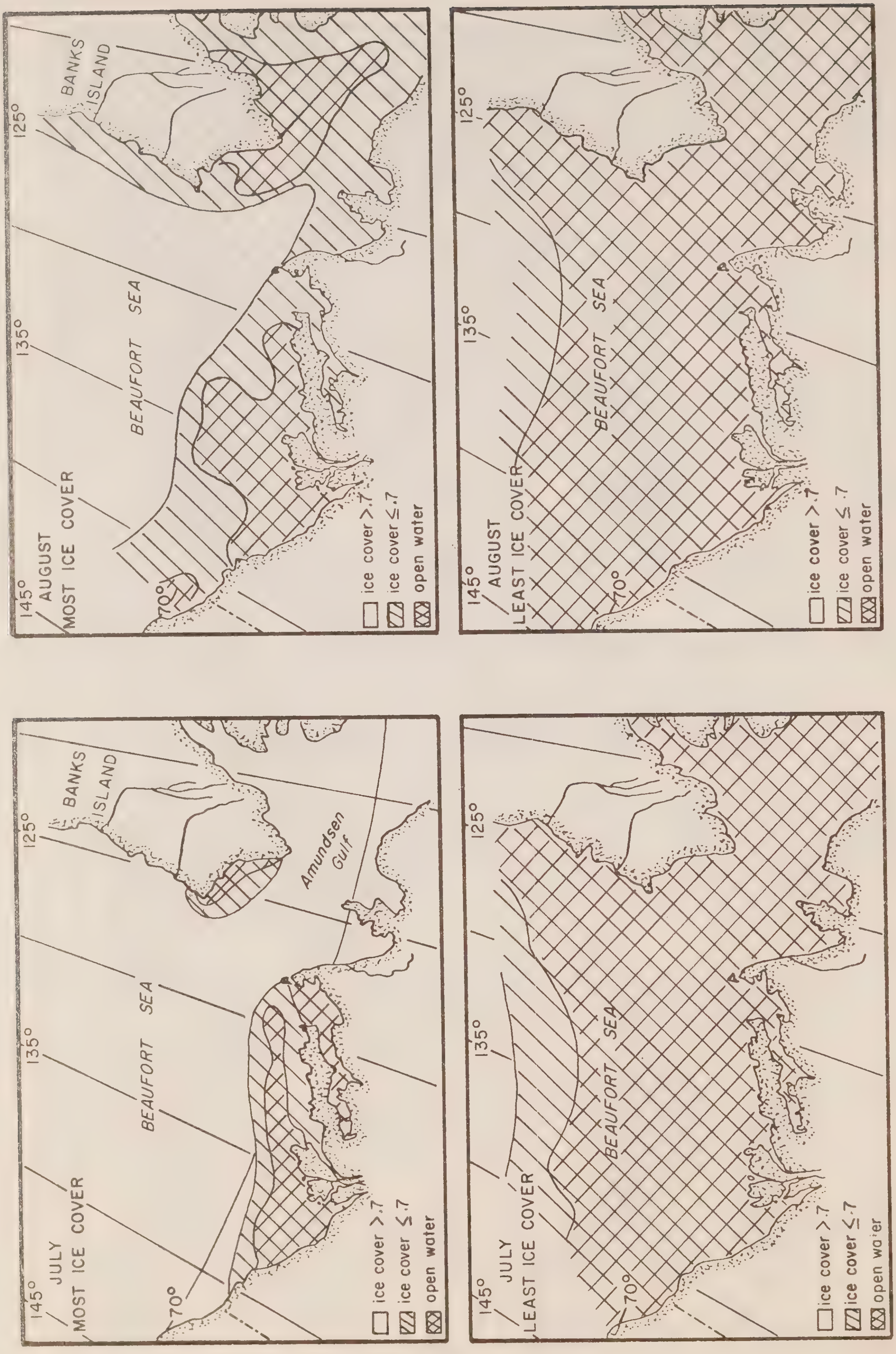

AUGUST
MOST ICE COVER
AUGUST
LEAST ICE COVER
JULY
MOST ICE COVER
JULY
LEAST ICE COVER
BANKS ISLAND
BEAUFORT SEA
Amundsen Gulf
145°
135°
125°
70°
ice cover >.7
ice cover ≤.7
open water

Figure 30b

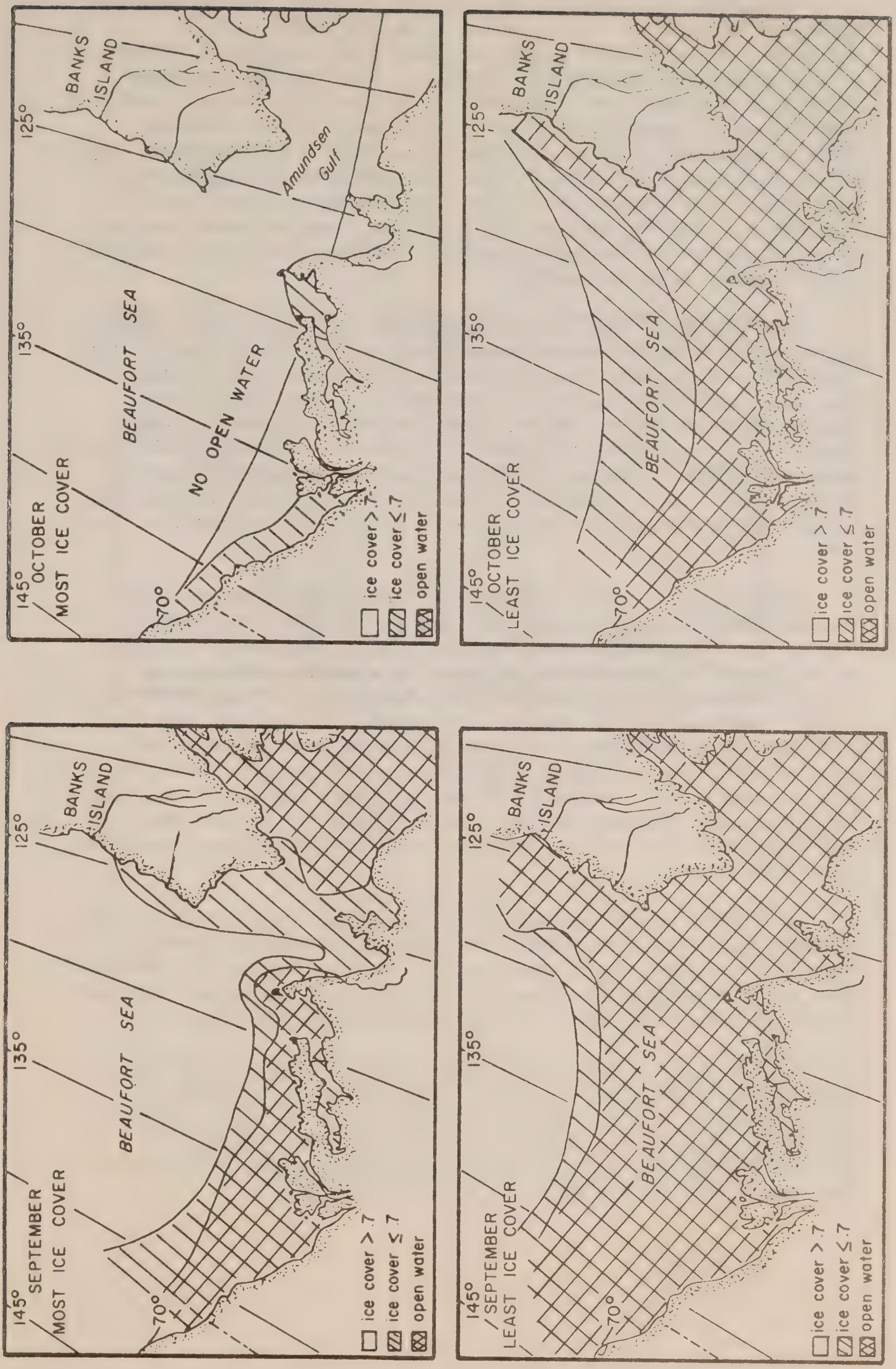

OCTOBER
MOST ICE COVER
145°
135°
125°
70°
BANKS ISLAND
Amundsen Gulf
BEAUFORT SEA
NO OPEN WATER
ice cover > .7
ice cover ≤ .7
open water
OCTOBER
LEAST ICE COVER
145°
135°
125°
70°
BANKS ISLAND
BEAUFORT SEA
ice cover > .7
ice cover ≤ .7
open water
SEPTEMBER
MOST ICE COVER
145°
135°
125°
70°
BANKS ISLAND
BEAUFORT SEA
ice cover > .7
ice cover ≤ .7
open water
SEPTEMBER
LEAST ICE COVER
145°
135°
125°
70°
BANKS ISLAND
BEAUFORT SEA
ice cover > .7
ice cover ≤ .7
open water

Figure 30c

Thus, sea ice consists of crystals of pure ice entrapping numerous small brine cells, whose size and number are variable. A sufficient number of such flat crystals provides a greasy appearance to the sea surface. As freezing continues, individual platelets of ice develop in quantity (frazil ice) and these tend to aggregate to form slush ice. (This slush may further aggregate to form pancake ice, flat round sheets of about 0.5 m or more in diameter.) The ice then freezes together to form floe ice or sheet ice. The rate of formation of ice is favoured by such factors as low salinity, lack of water mixing by winds or currents, shallow water, and the presence of old ice (which keeps the water calm).

The timing of the freeze-up depends to a very great degree upon the location of the shoreward edge of the polar pack, since initial ice formation usually occurs along the outer fringes of the pack (which are generally composed of older floes) and spreads southward from there. The Beaufort Sea anticyclone (page 103) can produce winds which move the permanent pack shoreward; an intensification of this effect can cause more rapid formation of ice. A delay in freeze-over can occur in the area of the Cape Bathurst polynya because of the active Beaufort Sea Gyre.

As the polar pack is driven shorewards by onshore winds in September, new ice begins to form in the shallow coastal areas. During November and December, this shorefast ice grows in thickness and increases its area in a series of seaward steps dependent partly on the characteristics of the offshore winds. Eventually the edge of the polar pack and the new fast ice converge, with the last area to freeze over being usually some 16 to 32 km offshore. To provide some appreciation of the general conditions involved, it may be noted that a 20- to 25-day period elapses between the mean date of the first occurrence of the first-year ice and the mean date of complete freeze-up along the Arctic coast.

In the Amundsen Gulf area, freeze-up usually begins in mid-October and progresses slowly because of the currents and the polynya. The Cape Parry area is the last to freeze up, the mean date being November 15 (Figure 31). The mean length of the ice season is about 280 days in the southern Beaufort Sea.

It may also be noted that any ice that survives for about three years generally reaches an "equilibrium" thickness of about 3 to 4 m. Subsequently, however, some seasonal variation can occur in this thickness. During each summer about 0.5 m will melt from the upper surface, and during each winter about the same amount will freeze to the bottom surface.

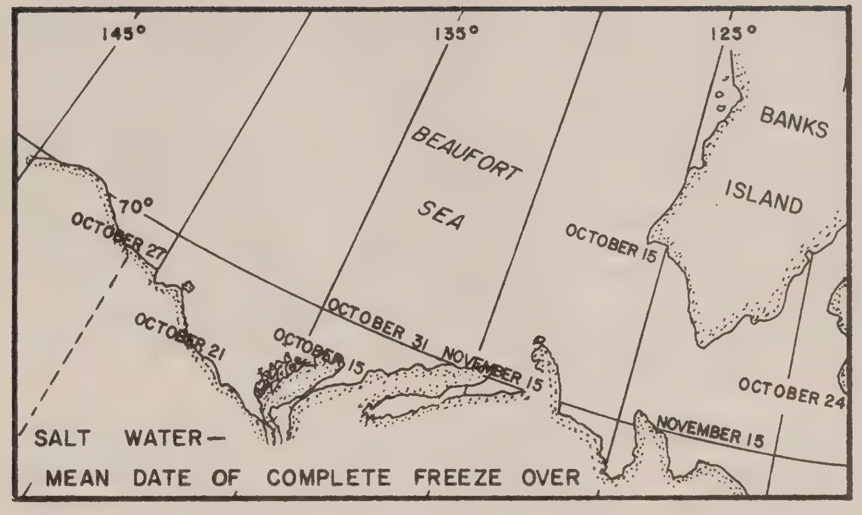

145°
135°
125°
BEAUFORT
SEA
BANKS
ISLAND
70°
OCTOBER 27
OCTOBER 15
OCTOBER 21
OCTOBER 31
OCTOBER 15
NOVEMBER 15
OCTOBER 24
NOVEMBER 15
SALT WATER—
MEAN DATE OF COMPLETE FREEZE OVER

Figure 31

Bottom Scouring by Ice

The sea bottom on the shelf can undergo extensive scouring as a result of the onshore or longshore movement of sea ice. Grounded floes are often encountered from winter through early spring, and even during the entire summer of a poor ice-year (see below). Under-ice projections such as pressure keels affect the scouring. Figure 32 indicates the variation, with location, of the number of scours observed per km.

Scouring in water of depth greater than about 50 m probably occurred during the end of the last glacial period (about 11,000 years ago), at which time sea level was much lower than it is at present. Trenches produced by scouring do not generally exceed 2 m in depth, but have been found in a few places to be as much as 6 m deep. It is found that the scour tracks have a predominant orientation of about 105° True (T). Scouring is common in water depths of 15 to 45 m, with the maximum activity at 30 m within the transition zone. (The deepest pressure keel so far observed drew 49 m of water.) It has been inferred from observations of the prevalence and heights of pressure ridges in the Beaufort Sea that each point on the 27-m depth contour on the continental shelf is likely to be contacted, but not necessarily scoured, once a year unless protected by bottom topography.

Another sea-bottom feature, perhaps related to scours or possibly to a sub-aqueous slump, was observed during the summer of 1975. A 20-m deep, rimmed, conical-shaped hole was observed in 100 m of water near the edge of the continental shelf north of Kugmallit Bay. The occurrence of this feature is presumed due to the vertical movement of an ice spike, possibly of glacial origin.

3.3.6 Climatology

The dominant factors which shape climate in a region are generally considered to be: the input of solar energy, the weather systems, the nature of adjacent land surfaces, and the topography. For the southeastern Beaufort Sea area, three manifestations of climate are considered to be of primary relevance to successful implementation of such operations as oil drilling: air temperature, winds and precipitation (together with cloud cover and fog). The salient characteristics of these three features are presented briefly in this section.

Air Temperature

During the lower temperatures that can be experienced in the Arctic, both men and machinery can be markedly and adversely affected. For example, in calm conditions, efficiency of outdoor manual labour at -30°C is only about a quarter of that at 20°C. Even the acclimatized native people gradually

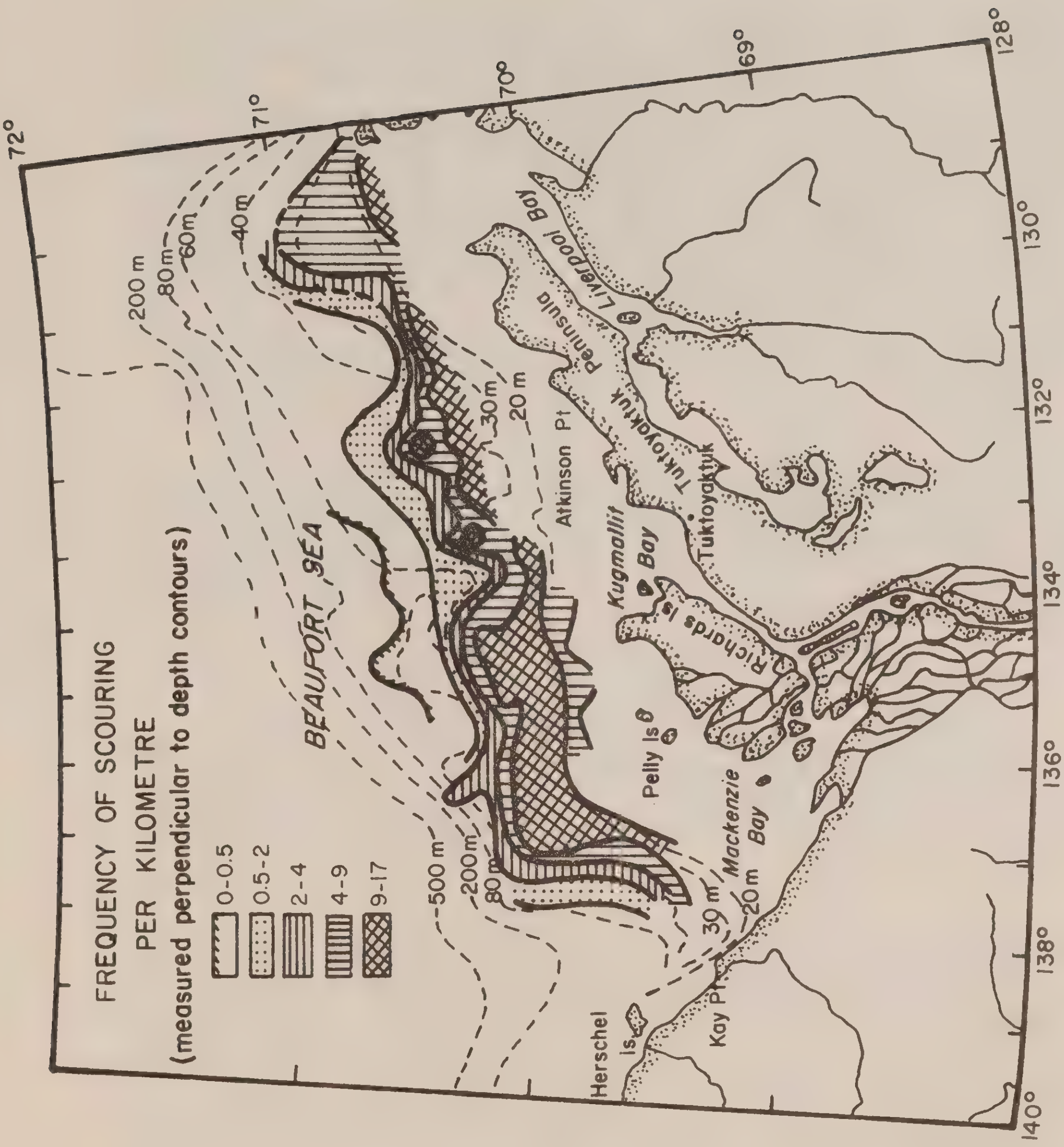

FREQUENCY OF SCOURING
PER KILOMETRE
(measured perpendicular to depth contours)
0-0.5
0.5-2
2-4
4-9
9-17
BEAUFORT SEA
72°
71°
70°
69°
128°
130°
132°
134°
136°
138°
140°
500 m
200 m
80 m
60 m
40 m
30 m
20 m
39 m
Liverpool Bay
Tuktoyaktuk Peninsula
Tuktoyaktuk
Atkinson Pt
Kugmallit Bay
Richards Is
Pelly Is
Mackenzie Bay
Herschel Is.
Kay Pt

Figure 32

become inactive at about -40°C in the outdoors. Below about -20°C, operation and maintenance of equipment can become increasingly difficult; for example, ordinary carbon steel, plastic and rubber tend to become increasingly brittle, and normal lubricants and fuels tend to gel. The effects are exacerbated by wind.

Air temperatures represent one aspect of the heat balance of the earth-atmosphere system. They are primarily a function of:

a) the input of solar energy. The Arctic regions receive no direct solar energy from late September to late March. However, during mid-summer (July and August) the total energy available to the region from the sun is approximately the same as at temperate latitudes; during this period, the effect of the small incident angle of the sun's rays upon the earth-atmosphere system (resulting in a small amount of energy being received per unit time per unit horizontal area of the earth) is compensated for by the increased length of the Arctic day;

b) the absorptive, reflective, radiative and scattering characteristics of the atmosphere and of the various surface features (e.g., vegetation, water, ice) of the Arctic area in question.

Because of the generally low temperatures, the Arctic winter is often defined for convenience as that period during which the daily mean temperature is less than 0°C. By this definition, the average length of the winter over the southern Beaufort Sea is about 275 days, extending from about mid-August through to mid-April. The length decreases to the south over the North American mainland, averaging about 250 days in coastal areas and about 200 days in the southern Mackenzie Valley, which is about 1100 km from the coast. The first two or three weeks following the end of winter are often referred to as "spring", and the two or three weeks immediately preceding winter as "autumn". The remainder of the year is considered to represent the summer season.

The coldest period of the year in the area occurs during the months December through February. Daily temperatures in February average about -30°C over the southern Beaufort Sea and in the Mackenzie Valley, respectively. During the months of December through February daily mean temperatures over the Beaufort Sea may be expected to drop to as low as about -23°C on over 80% of the days, to about -30°C on about 60% of the days and to -35°C on about 30% of the days.

The daily mean temperature commences to rise steadily at about the end of March and generally attains a maximum in July. In that month, values remain within a very narrow range (2° - 5°C) over the Beaufort Sea because of the moderating effect

of the ocean waters. However, temperatures can rise to about 20°C in the southern Mackenzie Valley. During July through September, the daily temperature over the southern Beaufort Sea to Amundsen Gulf shows a minimum relative to the neighboring land. At coastal locations, temperatures during the summer may be expected to drop close to freezing point whenever onshore winds occur; however, during offshore winds which have passed over large land surfaces, values from about 7° to 13°C are more likely. This large air-temperature variability at the coast, resulting from the sensitivity to wind direction, represents the extreme for the area during the summer.

The summer temperature regime in the southern Beaufort Sea area breaks down in late August with the onset of colder weather. During the autumn, there occurs a period during which the air temperatures over open water are warmer than those at land stations. This moderating effect will vary according to the amount of open water in the Beaufort Sea, which can vary markedly in extent and time of onset from year to year. The temperatures then decrease relatively uneventfully to the succeeding winter's minimum.

The range in daily temperatures in the area is appreciably greater over land than over the sea, 10°C or more and about 5°C respectively; it is everywhere greatest during the winter months. The seasonal variation in the monthly mean temperatures is about 35°C over the Beaufort Sea, as opposed to about 45°C in neighboring continental areas.

Winds

Winds can affect industrial activity in the Arctic in diverse ways. They can, for example, markedly exacerbate the cold temperatures (the wind-chill factor). They can hamper the work of supply vessels or of anchored drillships, by the production of waves or the drift of ice. They can either create barriers to travel on land, or facilitate such travel by helping to maintain sufficiently strong ice or snow cover. Persistent features of weather, together with the effects of topography, combine to produce the prevailing winds; the directions may be deduced from the orography and/or from the weather systems themselves.

In winter, the dominant air circulation over the Beaufort Sea area is essentially anticyclonic. In early winter the anticyclone is usually located over the Mackenzie River Basin and the western islands of the Canadian Arctic Archipelago; by late winter it has migrated eastward to the vicinity of Hudson Bay. At this time frontal lows seldom penetrate the region. However, there are exceptions; high altitude airflow patterns may steer lows into the area during early or late winter (October - November, March - April), while the major Aleutian Low in the

North Pacific Ocean may send secondary lows during December, January and March.

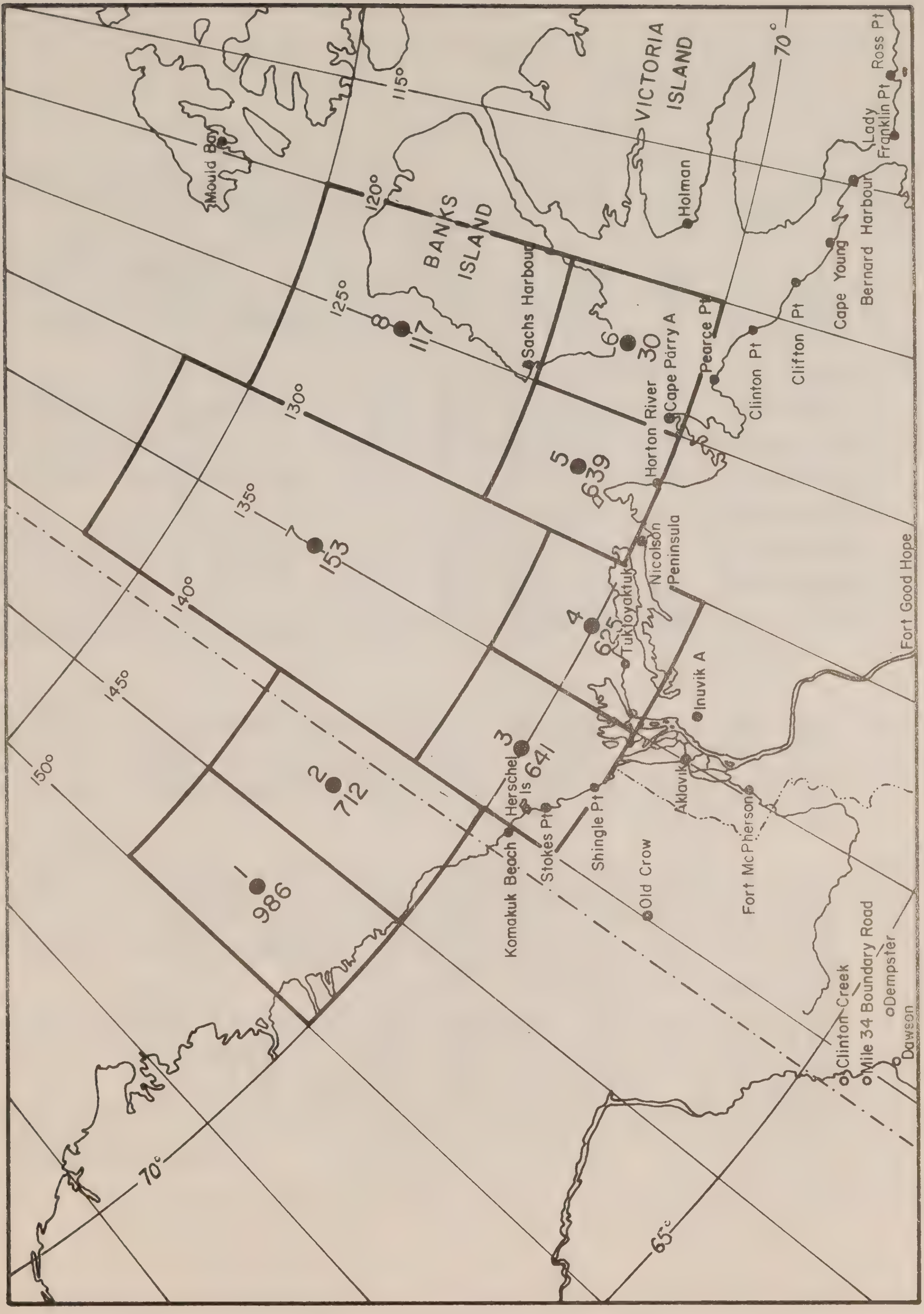
During the remainder of the year, and especially in July and August, cyclonic activity is far more evident, especially during May (although not necessarily severe); the anticyclone weakens and migrates northward. Numerous frontal lows originating in Siberia or the Bering Sea move eastward or southeastward across the area, as do any cyclones of Pacific origin. In the late summer lows tend to move along a corridor centred at about 70^{o}N, i.e., along the southern coast of the Beaufort Sea.

The available data suggest the following basic characteristics of the wind régime in the southeastern Beaufort Sea area:

a) The most severe winds (considered to be those of speed greater than about 50 km/h) occur most frequently in the autumn and winter.

b) The stormiest period of the year normally occurs in September through November; however, this period may be shifted by as much as a month in either direction.

c) Figure 33 displays several areas within the southeastern Beaufort Sea. These areas have been used to indicate general wind speed conditions over the Sea during the summer as provided by ships' observations obtained during the period 1954-70. The points (numbered 1 to 8) characterizing the areas indicate the plotting locations assigned in such a way as to maximize the data for a given area. The number immediately below a plotting point represents the total of hourly reports obtained throughout the corresponding area during the period. Table I indicates the percentage probability - during July through September - of the hourly wind speed being equal to or greater than the values given (km/h).



VICTORIA ISLAND
BANKS ISLAND
Mould Bay
Holman
Sachs Harbour
Ross Pt
Lady Franklin Pt
Bernard Harbour
Cape Young
Clifton Pt
Pearce Pt
Cape Parry A
Horton River
Nicolson Peninsula
Tuktoyaktuk
Inuvik A
Fort Good Hope
Aklavik
Fort McPherson
Shingle Pt
Old Crow
Stokes Pt
Herschel Is
Komakuk Beach
Clinton Creek
Mile 34 Boundary Road
Dempster
Dawson
115°
120°
125°
130°
135°
140°
145°
150°
70°
65°
8
117
6
30
5
639
7
153
4
625
3
641
2
712
1
986

Figure 33

TABLE I

	Percentage Probability							
	1	5	10	20	50	70	90	95
Grid Point 1	-	122	72	39	11	6	2	-
Grid Point 2	80	41	28	19	7	4	2	-
Grid Point 3	67	39	28	20	11	7	4	2
Grid Point 4	81	52	35	24	13	7	4	2
Grid Point 5	70	43	31	24	13	7	6	2
Grid Point 6	89	48	35	24	11	7	4	2
Grid Point 7	61	37	30	22	13	9	6	4
Grid Point 8	68	43	33	24	13	9	6	4

d) These data indicate that, during July through September, larger hourly wind speeds occur more frequently over the eastern than over the western Beaufort Sea; about half of the speeds exceed 15 km/h in the former part, while half exceed about 6 km/h in the latter.

e) Table II contains the corresponding values for seven selected land stations in the southeastern Beaufort Sea - Mackenzie Valley area, and covers periods December through February, March through May, June through August, September through November, or combinations of these. Cape Parry data are quite representative of the wind-speed regime of the eastern open Beaufort Sea, while stations along the Mackenzie Valley are more similar to those in the western Beaufort Sea. (Only the first two of these seven stations could be shown in Figure 33. The remaining ones are located in the upper Mackenzie Valley; for example Fort Smith, the most southerly station, is at 60^{o} 1.2'N, 111^{o} 33,6'W.)

TABLE II

Percentage Probability	1	5	10	20	50	70	90	98
CAPE PARRY A								
December through May	64	43	35	27	16	11	8	5
June through August	51	37	31	26	18	13	10	6
September through November	64	45	37	29	18	13	10	6
INUVIK A								
December through February	29	16	13	10	5	3	2	-
March through May	34	22	19	14	10	6	5	3
June through August	37	26	21	16	10	8	5	3
September through November	40	24	18	13	8	5	3	2
NORMAN WELLS A								
December through February	53	31	22	16	8	8	3	2
March through May	48	31	24	18	10	6	3	2
June through August	43	29	22	18	11	8	5	3
September through November	43	27	22	16	10	6	3	2
FORT SIMPSON								
December through February	32	21	16	13	8	5	3	2
March through May	29	22	19	16	11	10	6	5
June through August	32	22	19	14	10	6	5	3
September through November	27	21	18	16	11	10	6	5
HAY RIVER A								
December through February	39	24	18	13	8	5	3	2
March through May	34	23	18	14	8	6	5	3
June through August	42	27	21	16	10	6	5	3
September through November	35	26	21	18	11	8	6	5
YELLOWKNIFE A								
December through February	43	29	24	19	11	8	6	3
March through November	48	34	27	23	14	11	8	5
FORT SMITH A								
December through May	35	24	21	16	11	8	5	3
June through November	37	24	21	16	10	8	5	3

f) Maximum offshore wind speeds over the Beaufort Sea have been estimated for various durations and return periods. "Extreme-value" statistics have been used to provide the return periods. (A return period of x years for a wind of given speed and duration signifies that such a wind may be expected to occur once every x years.) Values are provided in Tables III and IV for periods June through October and November through May, respectively. For the former period, open-water characteristics have been assumed, and for the latter period, the presence of relatively smooth ice. Only Cape Parry data have been utilized in the preparation of Tables III and IV. Data from Tuktoyaktuk and Sachs Harbour, however, provide results only slightly different. Thus the values of offshore extreme winds are indicated to be quite uniform at least over the southern and eastern parts of the Beaufort Sea. The presence of only negligible information in the northwestern portion of the Sea makes the results uncertain in application to this area. As the analysis supplying the estimates is based on 10 to 15 years of data, the values calculated for return periods much longer than about twice this interval must be viewed with caution.

TABLE III

Duration (h)	Return Period (y) 2	5	20	100
1/60	107	120	137	155
1	85	96	109	124
6	74	83	94	107
12	67	76	87	98
24	63	70	80	91

TABLE IV

Duration (h)	Return Period (y) 2	5	20	100
1/60	117	129	148	168
1	92	104	118	135
6	81	91	104	118
12	74	81	94	107
24	68	76	87	98

g) For the case of strong winds (those having gusts greater than about 50 km/h), use of 10-to-15 year series of observations from Cape Parry, as well as from Tuktoyaktuk and Sachs Harbour, has provided an estimate of the percentage directional frequencies to be expected over the Beaufort Sea. These are shown in Table V.

TABLE V

Direction	NE	E	SE	S	SW	W	NW	N
Percent	5	20	10	5	5	20	30	5

h) For moderate winds (those having speeds between about 25 and 50 km/h), the most frequent directions, in order of importance, can be given for several coastal stations around the entire Beaufort Sea (Figure 33):

1) Komakuk Beach: west and east
2) Shingle Point: south-south-west, west-north-west, and east-southeast
3) Tuktoyaktuk: west-northwest or northwest, and east-southeast
4) Sachs Harbour: east and north-northeast.
5) Mould Bay: north-northwest

TABLE VI

Station	Wind Direction	Jan-Mar	Apr-June	Jul-Sept	Oct-Dec	Years of Data
Tuktoyaktuk	NNE	12	29	26	14	20
(Mainland	ESE	38	33	34	35	35
Coastal)	SSW	15	8	11	18	13
	WNW	30	26	27	24	27
Shingle Point	NNE	7	18	13	8	11
(Mainland	ESE	22	21	22	21	21
Coastal)	SSW	26	15	28	32	25
	WNW	43	45	36	38	40
Sachs Harbour	NNE	24	29	24	27	26
(Banks Island-	ESE	43	38	33	35	37
Southeast	SSW	13	13	18	13	14
Coastal)	WNW	19	17	23	22	20

i) A detailed breakdown of percentage frequencies of wind direction for three southeastern Beaufort Sea coastal stations - Tuktoyaktuk, Shingle Point and Sachs Harbour - is provided in Table VI. Four three-month periods are considered. The number of years of information used to obtain the results is also shown. A generally high frequency of winds from the WNW and ESE directions was quickly evident in the original data; these two directions, therefore - plus the directions SSW and NNE - have been used as central values for the four quadrants.

j) In the course of the two summers involved in the Beaufort Sea Project, evidence was obtained for the occurrence of several specific characteristics, during August through mid-September, of the nearshore winds off the Mackenzie Delta and the Tuktoyaktuk Peninsula. In summer, the weather can vary considerably from year to year; it appears, however, from the Beaufort Sea Project studies that steady northwest and steady east winds predominate both in strength and duration during this time. In 1975, for example, 63% of the winds near Pelly Island were from the west and 37% from the east (cf. Table VI).

k) The frequency and strength of northwest storms appear to be paramount in controlling the average summer climate, as well as the ice conditions during the period. Such a storm is usually caused by the passage of a low pressure system from west to east across the northern Beaufort Sea. Associated wind speeds can attain values of over 35 km/h for extended periods. As the low moves eastward across the sea, the winds tend to swing from southwest to west to northwest so that the wind direction during such a storm may actually change by 90 degrees - from about 225°T to 315°T. A period of several days, or even weeks, of calm or light winds often follows such a storm.

l) The other strong winds that have been observed in the area are easterlies and northeasterlies, accompanying the passage of a high pressure area from east to west. In mid-September 1974, easterly winds of greater than about 30 km/h were recorded continuously for more than a week.

m) In summer 1975, for example, four northwest storms of average wind speeds greater than about 30 km/h occurred; however, only two significant northeast storms took place.

n) Coastal or open water areas have the most frequent strong winds, and sheltered areas the least. In addition, the wind over large water bodies is generally much stronger than that occurring simultaneously at coastal or at inland locations. This effect is most likely during certain conditions, such as the passage of a cold front through the area in question. Under such situations, the wind may be two to four times stronger than that at the coast. Winds may be enhanced even

further by coastal topography, and move nearly parallel to the shore; the effect can extend as far as 40 km offshore.

o) Mean monthly wind speeds decrease southward from the Arctic mainland coast - from about 17 to 21 km/h at the coast to about 10 to 12 km/h in the southern Mackenzie Valley. The variability is large at all locations monitored; at the coast the standard deviation ranges from about 60% to 90% of the mean value, with the largest deviations occurring in winter.

p) The maximum such means generally occur in spring and autumn along the coast and in summer in the Mackenzie Valley.

q) The largest hourly wind speeds occur on the Arctic Coast (about 95 km/h); corresponding values in the Mackenzie Valley generally range from about 55 to 70 km/h.

r) A given wind speed persists longest in winter and spring; however, the greater the wind speed the shorter its duration. For example, strong winds generally persist for less than about 13 hours on the Arctic coast and for as little as four hours in the Mackenzie Valley.

s) At coastal locations, the percentage of time of calms appears to be largest in mid-winter (February, 40%), and least in summer (3%). Spring and autumn possess intermediate values, about 7% and 5% respectively. The maximum of calm periods in winter appears to offset the stronger winds and thus reduce the monthly mean wind speed for this time.

t) Winds in the coastal Beaufort Sea-Mackenzie Valley area can be greatly influenced, in strength and direction, by local influences such as steep, high coastal cliffs, major valleys, etc.; the resulting winds can be anomalous in nature to the prevailing air movements. For these localities, site-specific data and individual treatment of such features as return periods, are necessary.

u) Land and sea breezes can often develop along coastlines where significant temperature differences occur between land and water. In the Arctic, such differences tend to be seasonal in nature. In summer, they result in a wind component landward from ice or water; in winter they usually are insignificant.

v) Occasionally, however, when the pressure gradient is weak and skies are clear, diurnal land and sea breezes can occur and result in local offshore (morning) and onshore (afternoon) air movements.

w) The prevailing direction of winds in channels is usually along the channel axis. Speeds will increase in any constriction

in the channel, relative to those of either end of the constriction.

x) Cold dense air formed over a snow-covered area in the interior away from the coast may drain seaward along any channels. Such drainage winds, although generally of short duration, can be strong and extend several kilometres out to sea.

Cloud Cover, Fog and Precipitation

Thawing of surface layers of permafrost and the melting of frozen swamps can give the summer visitor to the southeastern Beaufort Sea the impression that the area is climatically extremely wet. However, portions of the expanse are in reality almost a polar desert; the annual precipitation is actually small, ranging from a mean of less than 125 mm over the Beaufort Sea itself to about 375 mm in the upper Mackenzie Valley.

Some salient features of the cloud cover, fog and precipitation appear to be as follows:

a) The occurrence of cloud in the area is determined primarily by the amount of open water, the air-sea temperature difference and the storm frequency.

b) The annual mean cloud cover varies with season. Both at the coast and inland, the value (all types of clouds included) decreases to a minimum of about 4/10 during the winter and increases to a secondary maximum in the spring; after a small decline, it then increases slowly to a principal maximum of about 8/10 in October at the coast and a few weeks later in the Mackenzie Valley. However, the variability about this mean is great throughout the year.

c) Over the Beaufort Sea in summer, the total cloud amount is least in July and greatest in September. The maximum frequency of heavy cover (7/10 to 10/10) moves coincidentally with the progress of the open-water condition.

d) The clear-to-about-6/10 state is consistent in the area during the period and a maximum in the obscured condition predominates throughout the western part of the sea.

e) The primary annual feature of the cloud cover over the southeastern Beaufort Sea and the adjacent Arctic coast is the extensive presence of quite low stratus and stratocumulus during the late summer and autumn. This cover results both from the state of the underlying surface and from the presence of a surface inversion. In coastal mountain areas it is associated with coastal winds and with upslope air motion.

f) The distribution of any high cloud over the sea and valley

in the summer is related chiefly to frontal activity and to cyclonic systems.

g) Stratus cloud is advected by the prevailing winds; both onshore and offshore flows therefore have a marked effect on local cloud conditions.

h) The general minimum cloud cover in winter results from effectively complete ice coverage of the Beaufort Sea, as well as from the overall presence of ground snowcover and of freezing conditions; the moisture content of the air is usually extremely low.

i) Fog ranks next to ice as a navigational hazard in the Arctic. In summer, fog is common along coastal areas and reduces visibility. The type is primarily advection (sea) fog, which occurs when warm air is chilled during passage over extensive surfaces of ice or cold water. Evaporation from exposed water areas and saturated ground surfaces produces further cooling, and an inversion which inhibits mixing and keeps fog at the surface.

j) The presence of advection fog is quite dependent upon the strength of surface winds; it is more frequent when winds are light. During strong winds, such fog can be lifted to form low lying cloud.

k) Fog is widespread over the sea during the period when the ice is melting. As the melting season advances, the fog becomes more patchy, tending to be more frequent and dense at the edges of drifting ice - at which locations strong temperature gradients tend to enhance mixing. Such fog can occur for a maximum of about six to eight days per month along the coast.

l) Steam fog (Arctic "sea-smoke") forms when very cold air from the ice pack passes over areas of warmer open water in winter. It will therefore occur in the vicinity of open leads or cracks in the ice. The rate of evaporation from the water surface is large, while the capacity of the air to hold moisture is restricted by its low temperature; the excess moisture quickly condenses as fog.

m) Steam fog is usually observed during the period October through April, is relatively localized and usually does not persist for more than a few miles downwind from the area of formation. This fog may serve the purpose of informing the navigator of the presence of open water at a distance.

n) Ice fog, the "smog problem" of the north, is another cause of reduced visibility. This type usually results from the direct sublimation of moisture on hydrocarbon particles. It occurs rather infrequently at present in the Canadian

Arctic because of the lack of both moisture in the very cold air and of hydrocarbon particles. However, both of these deficiencies may be overcome, locally at least, as human activity in the Arctic increases; pockets of such fog at settlements of working areas will quite probably ensue.

o) The mean total* of all forms of precipitation in the area ranges, as previously noted, from about 125 mm of water over the Beaufort Sea to about 250 mm in the lower Mackenzie River Valley. The year-to-year variability is large however, being greatest over the Beaufort Sea.

p) The mean annual number of days characterized by measurable (0.25 mm) precipitation (rain and snow) ranges from about 30 days over the Beaufort Sea to 90 to 120 days in the lower Mackenzie Valley.

q) The mean annual number of days with measurable rainfall ranges from almost zero over the Beaufort Sea to about 30 to 40 days along the lower Mackenzie Valley.

r) The mean annual number of days with measurable (1.15 mm) snowfall (5 mm of snow being taken to approximate 1 mm of water) ranges from a minimum of 30 over the Beaufort Sea to 60 to 90 in the lower Mackenzie Valley.

s) Rainfall in the Beaufort Sea - lower Mackenzie area is primarily confined, as in the Arctic generally, to the period June through September. The wettest months are July and August, with the annual maximum of 15 to 20 mm generally occurring in the latter month. Also the greatest variability occurs during these two months. Around the shores of the Beaufort Sea the total annual rainfall appears to range from about 45 to 70 mm.

t) Over the Beaufort Sea area the wet period is due both to cyclonic activity and to available precipitable water, which maximizes at this time. Along the Arctic coast northward over the sea much of the summer precipitation is drizzle, with some shower activity resulting from convection.

u) Most rainfalls occur in the morning or late afternoon.

v) The mean annual snowfall ranges from about 625 mm (125 mm of water) along the shore of the Beaufort Sea to 750 to 1,000 mm (150 to 200 mm of water) in the lower Mackenzie Valley.

*Most means noted here have been obtained from about 30 years of data.

w) The significant snow season can be ten to eleven months long in the Beaufort Sea area.

x) The snowfall in the Beaufort Sea and lower Mackenzie Valley increases rapidly in autumn, with the maximum mean annual value occurring in October. About one-half of the mean annual snowfall occurs from September through December. The period October through December has the most days with snow.

y) Outbreaks of progressively colder air move southward in September and October, the stormiest months of the year in the Arctic. When they contact the relative warmth and the moisture of coastal waters, frequent instabilities - and the snowfalls characteristic of the period - result.

z) One hundred and twenty five to 250 mm of snow (25 to 50 mm of water) can fall during the October maximum.

aa) January and February are generally the driest months of the year. Any precipitation consists only of snow, and occurs on an average of two days at the Beaufort Sea coast and northward and up to 10 days in the lower Mackenzie Valley.

ab) A secondary maximum in snowfall occurs in April, values however, being less than about one-half of those for corresponding locations in October.

ac) Small daily totals of either rain or snow are far more frequent than large ones. Also there is a preponderance of relatively small monthly amounts.

. PHYSICAL OCEANOGRAPHIC CHARACTERISTICS

4.1 Water Properties and Masses

Many properties can, singly or in combination, be used to characterize natural sea water. The principal properties are generally taken to be salinity (S), temperature (T), and a quantity that can be derived from these - density (ρ_t). Other important but secondary properties often considered are dissolved oxygen content and turbidity. Such properties can be used to delineate the horizontal and vertical extent of, as well as the associated spatial and temporal variability in, the water masses present in a specified area. These distributions in space and time can also provide information (primarily qualitative) upon both surface and sub-surface water movements. The knowledge obtained can be valuable in helping to determine the area or volume likely to be affected by spilled oil or other pollutants, as well as the speeds with which these materials will travel. A brief résumé of the spatial and temporal characteristics of salinity, temperature, density and (where possible) turbidity, as well as the associated variabilities, is presented below. The

Beaufort Sea in general is considered first, followed by a treatment of conditions over the continental shelf. It may be noted that the findings are based on only a modest amount of field data.

4.1.1 The Arctic Ocean

The Beaufort Sea in particular (and the Arctic Ocean in general) can be considered to consist of three major water masses: Arctic water, Atlantic water and Bottom water (Figure 34).

The Arctic Water Mass

This mass extends from the surface to a depth of about 200 m. It can be divided into three layers: surface, sub-surface and lower. The surface layer is much the same across the entire open Arctic Ocean. It extends from the surface to a depth of about 25 to 50 m. The salinity is strongly influenced by the melting or freezing of ice and has a relatively wide range - from about 28 to 33.5^{o}/oo. The temperature also is controlled by the melting or freezing of ice, which involves considerable heat transfer at constant temperature (the freezing point). Consequently, the temperature remains near the water's freezing point, which varies only from -1.5^{o}C at a salinity of 28^{o}/oo to -1.8^{o}C at a salinity of 33.5^{o}/oo. Seasonal variations in water properties are confined to this layer and range up to 2^{o}/oo in salinity and to 0.2^{o}C in temperature.

The sub-surface layer, bounded by the surface layer and by a depth of about 100 m, is characterized by a strong, permanent positive halocline (a significant increase in salinity with depth) between about 25 and 100 m. In the sub-surface layer overlying the Canada Basin (which includes the open Beaufort Sea) there is a characteristic temperature maximum at 75 to 100 m depth with a consequent minimum of about -1.5^{o}C at 150 m and then an increase in the deeper water. The temperature maximum is attributable to Bering Sea water entering the Arctic through the Bering Strait. This water is warmer than the Arctic surface layer but is slightly denser because of its salinity. No such sub-surface temperature maximum is present in the water of the Eurasian Basin.

The lower layer of the Arctic water is essentially a mixing layer between the sub-surface Arctic water above and the Atlantic water below.

The Atlantic Water Mass

Below the halocline within the Arctic water mass, the salinity increases slowly with depth to about 34.9 to 35.1^{o}/oo. The temperature continues to increase with depth to a maximum of about 0.5^{o}C - at about 350 m in the Eurasian Basin and about 500 m in the Canada Basin - and then decreases to less than 0^{o}C at about 900 m. The layer warmer than 0^{o}C is termed the

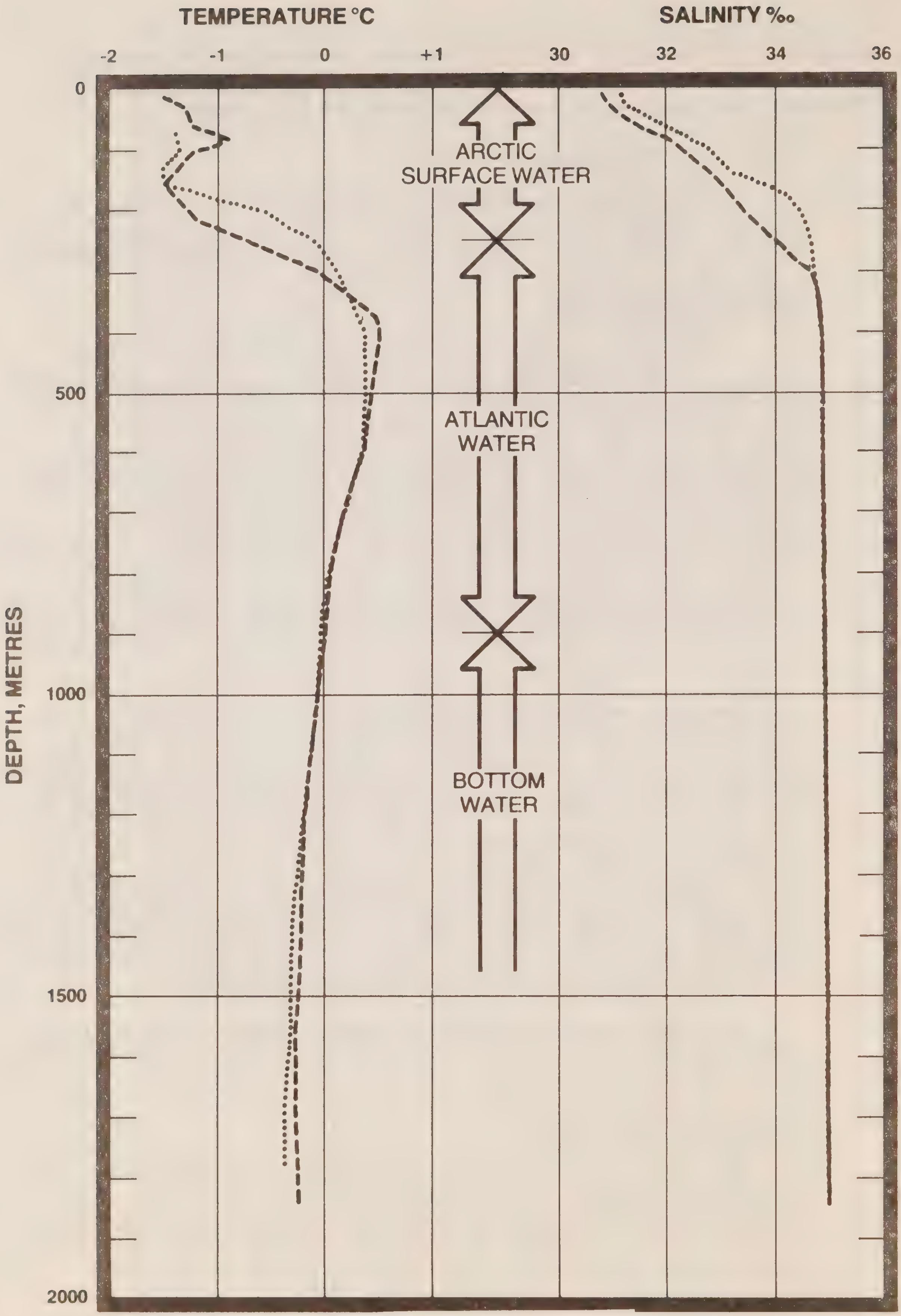

TEMPERATURE °C
SALINITY ‰
-2
-1
0
+1
30
32
34
36
0
500
1000
1500
2000
DEPTH, METRES
ARCTIC
SURFACE WATER
ATLANTIC
WATER
BOTTOM
WATER

Figure 34

Atlantic water mass. Thus this mass has a temperature higher than that of the water above or below it. It is so named because its source is the North Atlantic surface water which moves through the Norwegian and Greenland Seas as the Norwegian and West Spitsbergen Currents, respectively. Within the Arctic Ocean this water is found beneath the Arctic water mass, because of its great density.

The Bottom Water Mass

The Bottom water mass extends from about 900 m depth to the bottom - as deep as about 3,900 m in the Canada Basin and about 4,500 m in the Eurasian Basin. It composes about 60% of the total water volume of the Arctic Ocean. The salinity range throughout the mass is very small, being from only 34.93 to 34.99^{o}/oo, and in any particular area the change in the vertical direction is smaller than this. If anything, the tendency is for a very slight increase in salinity with depth.

The temperatures everywhere are less than 0^{o}C. They decrease with depth to a minimum of about -0.4^{o}C to -0.5^{o}C at about 2,500 m in the Eurasian Basin. Beneath the minimum, there is an increase to the bottom, of about 0.2^{o}C. This is due to heating by adiabatic compression (at a rate of about 0.1^{o}C per 1,000-m increase in depth). It is believed that this bottom water is also of Atlantic origin and has moved in from the Norwegian Sea. The Lomonosov Ridge effectively separates the two basins, as previously noted. The Canada Basin is filled therefore with that portion of Eurasian Basin water above the sill depth of the Ridge - about 1,400 to 1,500 m. This fact accounts for the somewhat higher temperature of the water in the Canada Basin.

On mean annual basis, the prevailing temperature and salinity characteristics of each water mass have apparently remained unchanged for at least the past 80 years or so. It may be noted that, in the waters deeper than about 180 m, the density is basically a function of salinity alone, temperature having a relatively small effect.

4.1.2 The Eastern Continental Shelf of the Beaufort Sea

The waters overlying the Canadian Continental Shelf of the Beaufort Sea and the adjoining portion of the continental slope are basically those of the Arctic water mass. However, especially in the near-surface waters, various features associated with the nearby continent in concert with meteorological factors such as wind can result in much more marked fluctuations of property within the mass than is the case in the open Arctic. As the oceanographic properties and characteristics of these waters will be of prime relevance to any oil drilling operations conducted on the shelf, they are discussed in some detail in this section.

The primary sources of the Arctic water mass are the marginal seas of the Arctic Ocean and the Bering Sea. These provide the previously noted characteristic salinities and the range with depth of about 5.5^{0}/oo (28 to 33.5^{0}/oo). In the open Arctic Ocean the seasonal changes in this mass are modest and are confined essentially to the surface layer. The continental seas - the Laptev adjacent to Siberia and the Beaufort off Canada and Alaska - are in turn strongly modified by the large rivers emptying into them, especially near the coast. The Lena River entering the Laptev Sea and the Mackenzie entering the Beaufort Sea are prime examples.

In the Beaufort Sea, spatial and temporal variability in the salinity of waters in the vicinity of the Mackenzie River is found to govern variability in density. Differences in salinity are determined by such factors as fresh water inflow and mixing due to wind. The variability, which is again confined essentially to the surface layer, is generally much larger than that occurring at corresponding times in the open Arctic Ocean. Variability much larger than that present in the offshore areas also can occur in the temperature of the surface layer; however, although temperature in itself is important in many aspects of marine science and technology, its variability does not play a significant role in altering the density in Arctic waters. Therefore, variabilities in salinity and density basically parallel one another. Only salinity (and not density) will be treated in this section; however, the corresponding, although implicit, relationship between the two properties should be constantly borne in mind. It may be noted that, in present day oceanographic work, salinity is somewhat easier to determine than is density.

Examples of the typical structure (vertical distributions [profiles]) of the primary physical oceanographic properties S and T that are believed to predominate over the Canadian Beaufort Continental Shelf and/or the immediately adjacent continental slope during the year are shown in Figures 35, 36 and 37.

Salinity

At depths between about 50 and 200 m, the latter representing the depth of the Arctic water mass, the salinity increases slowly and linearly with depth. Typical values at the locations sampled were about 32^{0}/oo at the shallower limit and about 33 to 33.5^{0}/oo at depth. These latter values approximate the base salinity of the deeper portions of the Arctic water mass. The variability at any depth in this interval appears to be no greater than about 1^{0}/oo. This range can occur throughout a variety of temporal scales. Profiles taken at irregular intervals in summer during the period 1951-74 (Figure 35), during spring and summer (Figure 36), and hourly for up to 53 hours in summer and 89 hours in spring (Figure 37a and b), all indicate essentially similar variability ($\sim$ 1^{0}/oo) in the lower layer.

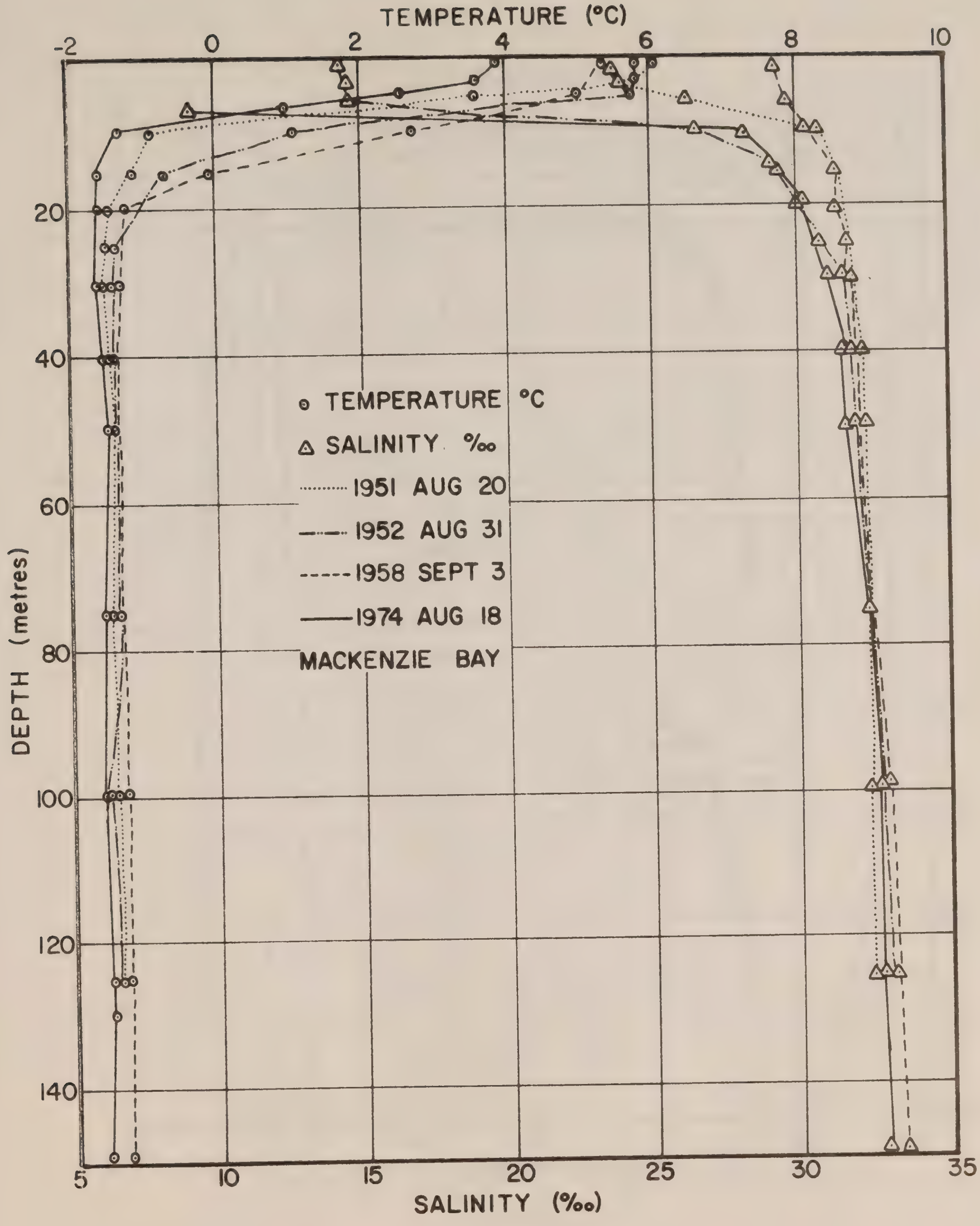

TEMPERATURE (°C)
-2
0
2
4
6
8
10
DEPTH (metres)
20
40
60
80
100
120
140
TEMPERATURE °C
SALINITY ‰
1951 AUG 20
1952 AUG 31
1958 SEPT 3
1974 AUG 18
MACKENZIE BAY
5
10
15
20
25
30
35
SALINITY (‰)

Figure 35

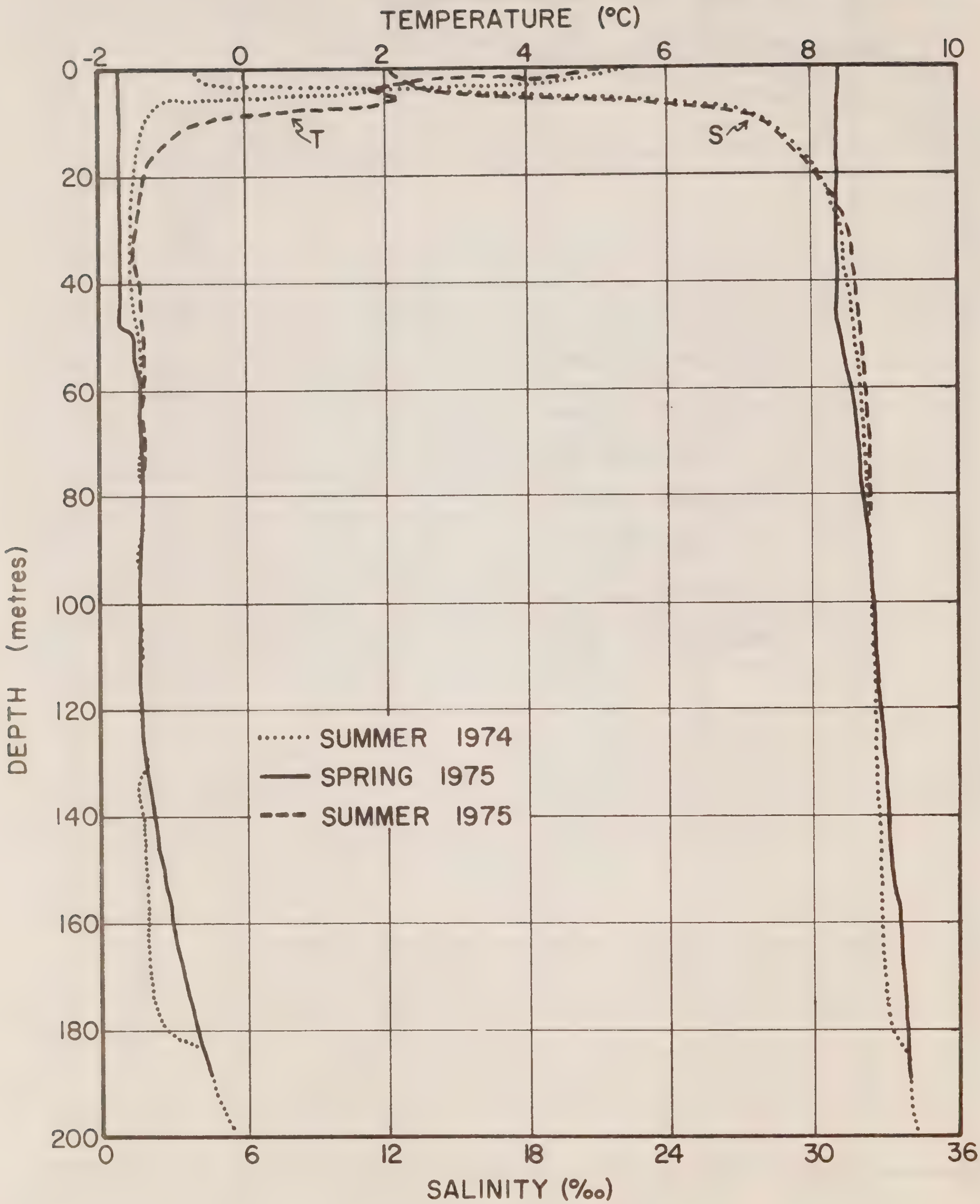
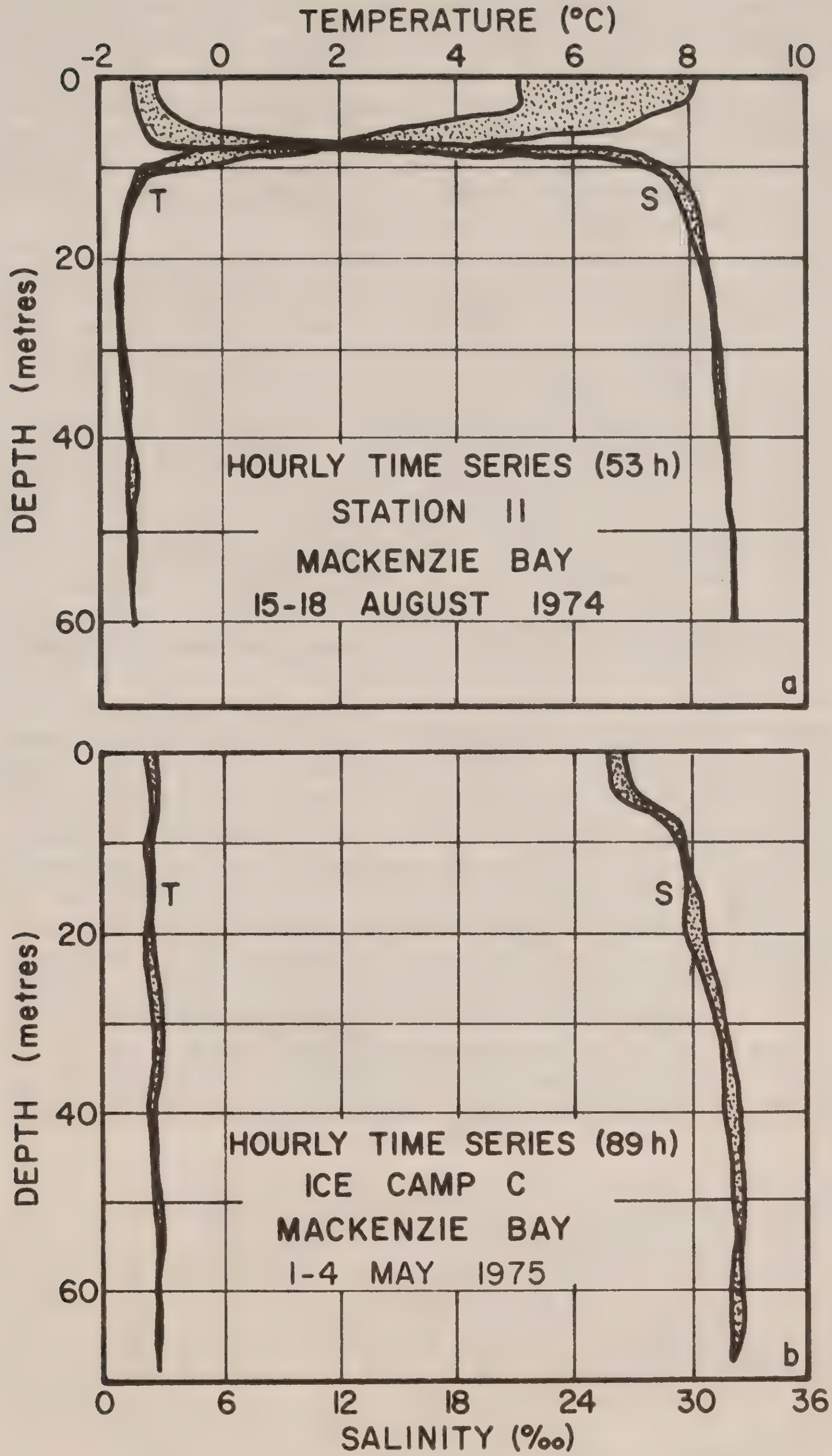

TEMPERATURE (°C)
-2
0
2
4
6
8
10
T
S
0
20
40
60
80
100
120
140
160
180
200
DEPTH (metres)
SUMMER 1974
SPRING 1975
SUMMER 1975
0
6
12
18
24
30
36
SALINITY (‰)

Figure 36



TEMPERATURE (°C)
-2
0
2
4
6
8
10
0
20
40
60
DEPTH (metres)
T
S
HOURLY TIME SERIES (53 h)
STATION 11
MACKENZIE BAY
15-18 AUGUST 1974
a
0
20
40
60
DEPTH (metres)
T
S
HOURLY TIME SERIES (89 h)
ICE CAMP C
MACKENZIE BAY
1-4 MAY 1975
b
0
6
12
18
24
30
36
SALINITY (‰)

Figure 37

By contrast, during the summer at least, the salinity in the surface layer has been found to be as low as $3^{o}/oo$ or as great as about $30^{o}/oo$ (Figures 35 and 37). The lesser values would be expected to be most common during the freshet of the Mackenzie River, although they can occur later in the season due to damming of river water by polar-pack ice or to time-localized increases in river outflow. The low values imply an increase in the magnitude of (the salinity difference through) the positive halocline characterizing the sub-surface layer of the Arctic water mass. The surface layer can be very thin, typically five to 10 m; its proximity to the isohaline state is a function of the degree of wind mixing and perhaps of other factors.

During the winter (conditions of almost complete ice cover) the halocline will become much less marked than in summer or even vanish altogether. The salinity will increase greatly because of both sharply reduced fresh water run-off and formation of sea ice; temperatures will decrease because of surface-induced cooling. Convective overturn resulting from these features will therefore tend to produce uniform (isohaline and isothermal) water throughout the surface layer associated with the Arctic water mass, as well as much of the sub-surface layer. The horizontal distribution of salinity at the surface is another presentation useful in revealing the gross interaction between such factors as fresh water run-off, ice cover and wind (Figure 38). A few basic conditions can be recognized. Figure 38 a depicts surface salinity in the presence of strong encroachment of the Arctic pack ice into the southeastern Beaufort Sea in summer after an extended period of onshore winds. The salinity between the shore and the pack ice (generally involving distances of up to only 120 km) has a very modest range; values are between about 2 and 5 $^{o}/oo$. The conditions probably result from the damming of emergent fresh water by the ice pack. In Figure 38c, the salinity over the shelf is seen to increase markedly to shoreward with values increasing by about $10^{o}/oo$ (from about 20 to $30^{o}/oo$) over a distance of about 110 km. The gradient (rate of change with distance) also increases to shoreward. This situation occurred just after a strong (40 to 50 km/h) easterly wind had blown for some time. This wind is presumed to be responsible for the observed surface salinity distribution by inducing a process known as upwelling.

(Theory suggests that the interplay between the Coriolis force and the wind stress acting on the ocean surface can lead to a net transport of water. This transport would be at about 90^{o} to the right of the wind direction (in the northern hemisphere) and could involve water between the surface and a considerable depth; it would be dependent upon such factors as wind speed and latitude. As replacement for the transported water, deeper

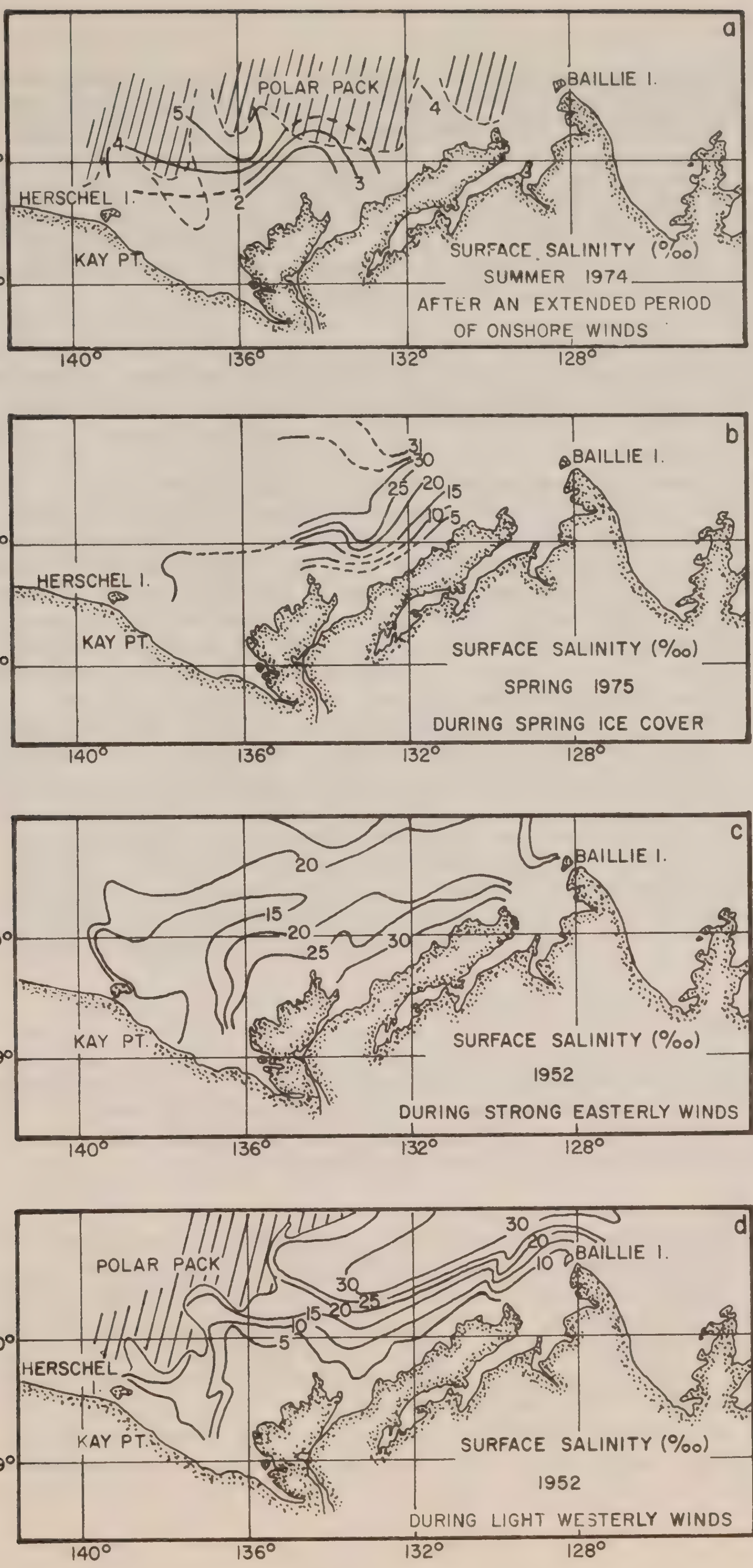

a
POLAR PACK
BAILLIE I.
HERSCHEL I.
KAY PT.
SURFACE SALINITY (‰)
SUMMER 1974
AFTER AN EXTENDED PERIOD
OF ONSHORE WINDS
b
BAILLIE I.
HERSCHEL I.
KAY PT.
SURFACE SALINITY (‰)
SPRING 1975
DURING SPRING ICE COVER
c
BAILLIE I.
KAY PT.
SURFACE SALINITY (‰)
1952
DURING STRONG EASTERLY WINDS
d
POLAR PACK
BAILLIE I.
HERSCHEL I.
KAY PT.
SURFACE SALINITY (‰)
1952
DURING LIGHT WESTERLY WINDS
70°
69°
140°
136°
132°
128°

Figure 38

water would move upward; this vertical motion is termed upwelling. The theoretically-derived characteristics of the process have been amply confirmed by field observations.)

In the present case, the strong easterly winds would have moved the shallower, brackish waters to the north away from the coast. The upwelled water, which would be more saline and/or colder than the displaced water, would be the cause of the higher salinities occurring near the shore.

A southerly wind could, in the case of strong stratification, move surface-layer water in the downwind direction. Replacement of this displaced water by deeper water in such conditions could also provide a salinity distribution basically similar to that shown in Figure 38c. Figure 38d, on the other hand, depicts a sharp summer increase of surface salinity seaward with values increasing from $\sim$ 5⁰/oo at the shore to $\sim$ 25⁰/oo 80 km away. Only a very light westerly wind was known to be present at the time. This condition indicates the near shore easterly movement of the emergent fresh water, believed to result primarily from the effect of Coriolis force. This would appear to be the preferred flow régime for this water in the absence of wind or in the presence of only weak air movements. The slight decrease in surface salinity near the ice pack is probably due to melt waters originating in the pack. Strong westerly winds would probably tend further to move (converge) fresh water into the near-shore area. Figure 38b indicates an example of the under-ice distribution of surface salinity. The values tend to be low near the shore to the east of the Mackenzie River mouth then increase sharply to seaward. The distribution is consistent with the concept of emergent fresh water moving essentially under the influence of horizontal pressure differences and of Coriolis force, the effect of wind upon the surface water being minimized by the overlying ice cover.

Temperature

At depths between 20 m and at least 120 m, the temperature structure over and for a considerable distance seaward of the continental shelf was found to be isothermal, at around -1.5^{o}C, throughout the year (Figures 35, 36 and 37).

The variability at any depth in this interval is suggested to be no greater than about 0.4^{o}C over time scales ranging from a few days to about 25 years. (The variability appears to be nearer 0.2^{o}C over the shorter time scales.) At depths of 120 m or more, according to location, the temperature is marked by a generally uniform increase with depth, apparently to a value of about 0^{o}C at 200 m; this latter depth approximates that of the bottom of the Arctic water mass.

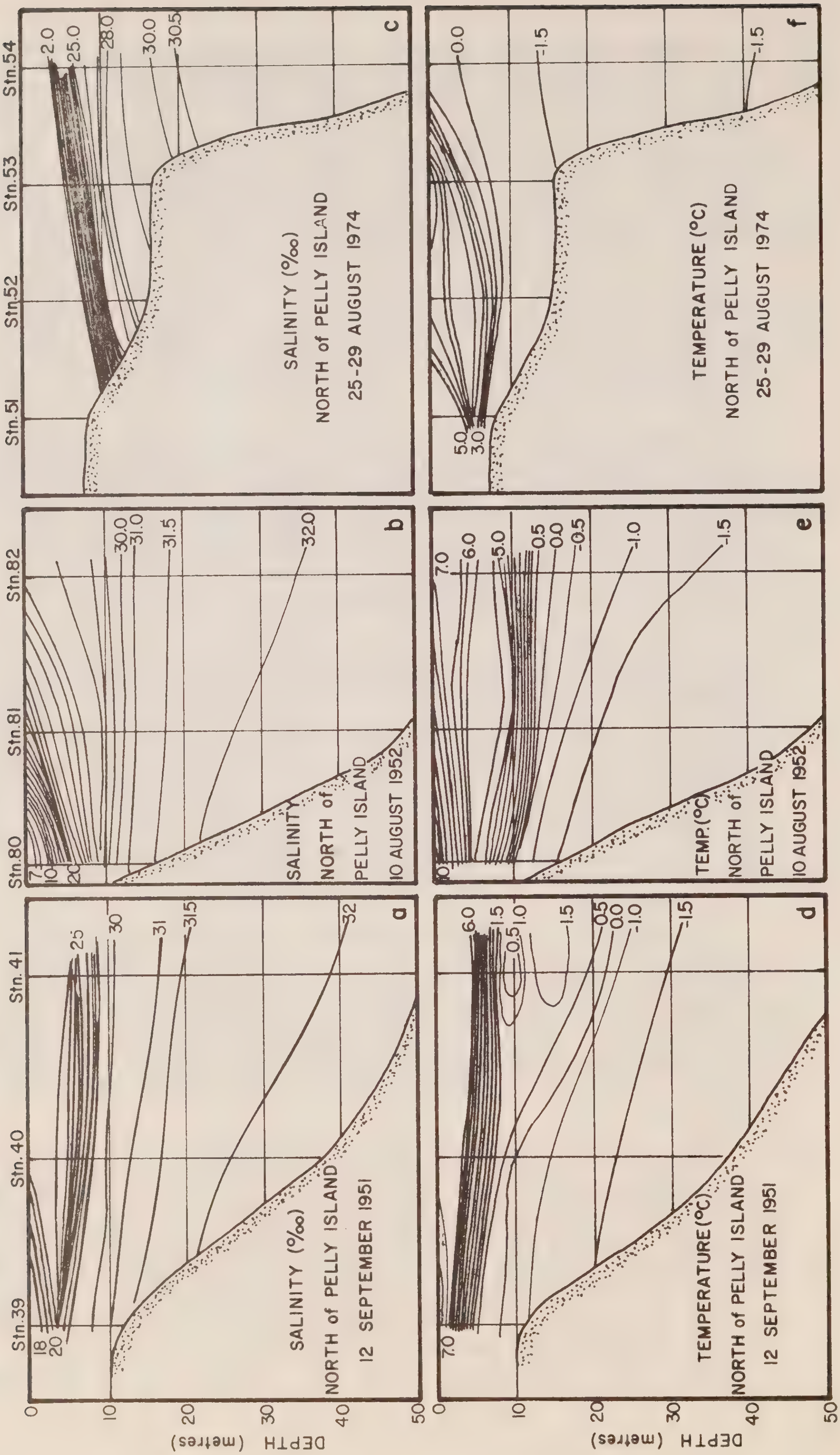
By contrast, the profiles of temperature at about 20 m reveal the presence of large variability over the year. In summer, the surface layer can become relatively warm. Values up to 9^{o}C have been recorded. This condition is due primarily to the presence of the relatively warm river water and/or retained insolation. During the summer, sunlight to warm the surface waters is present for much of each "24-hour" day, provided of course that thick or extensive cloud cover is not present. Mixing by wind, or convective overturn due to cooling, can result in an isothermal surface layer. Temperatures, especially those relatively near the shore, can become as low as 0^{o}C even in summer, because of the effect of such processes as upwelling. Ranges of 3^{o}C have been recorded over about a two-day period, and of 1.5^{o}C over a one-day period.

Roughly coincident in depth with the seasonal halocline is a seasonal negative thermocline, in which the temperature decreases markedly with depth. Temperature differences of 6^{o}C to 7^{o}C through a depth interval of 5 m or so have been recorded (e.g. Figure 37); however, a thermocline involving differences as small as 1^{o}C can be identified. The thermocline can vary in depth by a few metres during periods as short as a day, as can the halocline.

During the winter, this shallow seasonal thermocline vanishes. Temperatures can be near-isothermal to more than 150 m depth because of convective overturn. Throughout the depth interval previously occupied by the surface layer, water can even become slightly cooler than that below (e.g. by about 0.3^{o}C, Figure 37). The degree of this effect will be a function at least of the severity of the winter cooling in question. In spring, the shallow water immediately under the ice can become slightly warmer than that at depth due in general, perhaps, to the relative warmth of river water moving over the shelf.

For the variation of properties with depth, an insight somewhat more comprehensive than that provided by examination of individual profiles can be obtained by means of vertical cross sections. As an example, Figure 39 provides such cross-sections of S and T obtained at the same general location of the shelf during the summers of 1951, 1952 and 1974 respectively. The sections basically are perpendicular to the direction of the coastline.

The salinity data indicate that, while a seasonal halocline exists during each summer, its intensity - the vertical gradient as well as the difference of salinity through it - can vary markedly. Figures 39 a and b both indicate that part or all of the halocline sections also suggest the shoreward confinement, to greater or lesser degree, of brackish surface water - an increase in surface salinity to seaward being evident. This confinement and the accompanying shoreward encroachment of more saline offshore water could be produced, for example, by the action of



DEPTH (metres)
Stn.39
Stn.40
Stn.41
SALINITY (‰)
NORTH of PELLY ISLAND
12 SEPTEMBER 1951
a
Stn.80
Stn.81
Stn.82
SALINITY
NORTH of
PELLY ISLAND
10 AUGUST 1952
b
Stn.51
Stn.52
Stn.53
Stn.54
SALINITY (‰)
NORTH of PELLY ISLAND
25-29 AUGUST 1974
c
TEMPERATURE (°C)
NORTH of PELLY ISLAND
12 SEPTEMBER 1951
d
TEMP.(°C)
NORTH of
PELLY ISLAND
10 AUGUST 1952
e
TEMPERATURE (°C)
NORTH of PELLY ISLAND
25-29 AUGUST 1974
f

northerly winds moving a brackish layer in approximately the direction of the wind. Alternatively, westerly winds could bring about a net movement of water to the right of the wind direction - a convergence which would confine fresh water near the shore. Figure 39c indicates the presence of a wide, almost fresh, surface layer underlain by an extremely intense halocline. This feature suggests the formation of a pool of river water undergoing little mixing with the deeper more saline water. The pool could have resulted from the marked shoreward encroachment of pack ice with, concomitantly, both a reduced open-water area to contain the fresh water and a lessened degree of wind mixing of the fresh and saline waters. A slow vertical increase in salinity below about 20 m is common to all sections.

The temperature sections confirm the general presence of a shallow thermocline. In Figures 39d and e, surface layer conditions are marked by a coincidence of primary features in both the temperature and the salinity distributions. Figure 39f demonstrates the possibility of relatively marked horizontal temperature variability in the surface layer, a few degrees over the length of the cross section, in the presence of only a very small corresponding horizontal change in salinity. A near isothermal condition (at about -1.5^{o}C) is evident in the deeper water of all sections.

Turbidity and Suspended Matter

Turbidity (or its inverse, transparency or clarity) and the concentration of suspended matter are complementary factors of one aspect of sea - or freshwater - quality. For Beaufort Sea waters, especially those overlying the continental shelf, these quantities have significance in various operational and scientific aspects. Determination of surface-water turbidity - especially by broad-area scanning by remote photography from satellites or airplanes - can be instructive in the elucidation of the primary features of the surface circulation (Figure 40). Near-bottom values of turbidity can perhaps supply qualitative indications of the characteristics of the deeper circulation and/or the activity (e.g. slumping) of bottom sediments - the latter especially on steeper portions of the bottom. Such information can be of value during the construction and maintenance of artificial drilling islands. The degree of turbidity is of importance to the efficiency of underwater operations involving divers or submersibles. Surface-layer turbidity of minerogenic origin can indicate an inhibition of marine phytoplankton production and thus a possible disruption of the local marine food web. Alternatively, turbidity found to be of organic origin can perhaps aid in the determination of phytoplankton presence and production.

Figure 40

The fresh or brackish water originating from the Mackenzie River and tending to dominate the surface layer characteristics in the area in question carries a considerable minerogenic suspended sediment load, especially during the freshet period (Section 3.3.2). In terms of suspended load, the Mackenzie is the third largest entering the Arctic Ocean, being exceeded only by two Russian rivers, the Lena and the Ob. It contributes about 119 (10^6) tonnes of suspended matter annually, most of it during the freshet season. (By comparison, the Fraser River in British Columbia contributes about 18 to 23 (10^6) tonnes annually to B. C. coastal waters.)

The content of the suspended material throughout the water column has been directly determined during the late summer of 1975, off the Mackenzie Delta, in the vicinity of Herschel Island, and near the Mackenzie Canyon. The sampling was carried out primarily on three transects (A, K and N) - values being obtained from the coast to as far as 110 km offshore (Figure 41).

The vertical sections of suspended material, salinity and temperature associated with these transects are shown in Figures 42, 43 and 44. In general, the greatest concentrations of suspended material were found just off Kugmallit Bay (Figure 42 - Line A). Values at or near the surface ranged up to about 17.4 mg/L (milligrams per litre); sub-surface values exceeded 1.25 mg/L. Values somewhat to the west of Herschel Island were very much less, averaging only about 0.35 mg/L. The greatest values were in general found in the shallow waters.

Away from the near shore the values are usually less than those just noted. The greatest concentrations found (1.6 mg/L) occurred at, and somewhat below, the upper edge of the continental shelf, and thus represent "mid-depth" maxima. Such maxima were also found at several locations on the shelf itself. In the depression east of Herschel Island, values are close to 1.0 mg/L and are nearly uniform throughout the water column. Near the Mackenzie Canyon, surface values were found to be about 1.2 mg/L. Near-bottom values are apparently small (< 0.4 mg/L).

The distribution of suspended matter found appears to be compatible to an appreciable degree with the general circulation now believed to characterize the area (see Section 4.2).

A measure of the relative turbidity, defined here in terms of percent (%) light transmittance, has also been monitored at several locations. (Transmittance in air is assumed to be 100%.) Shallow profiles have been obtained in the vicinity of Stations 168 and 183 in summer 1974 and spring 1975 (Figure 45). Values at the latter time were obtained under the ice. As well, three transects were obtained during summer 1974: one from the shore to about 80 km offshore east of Kugmallit Bay, one across the

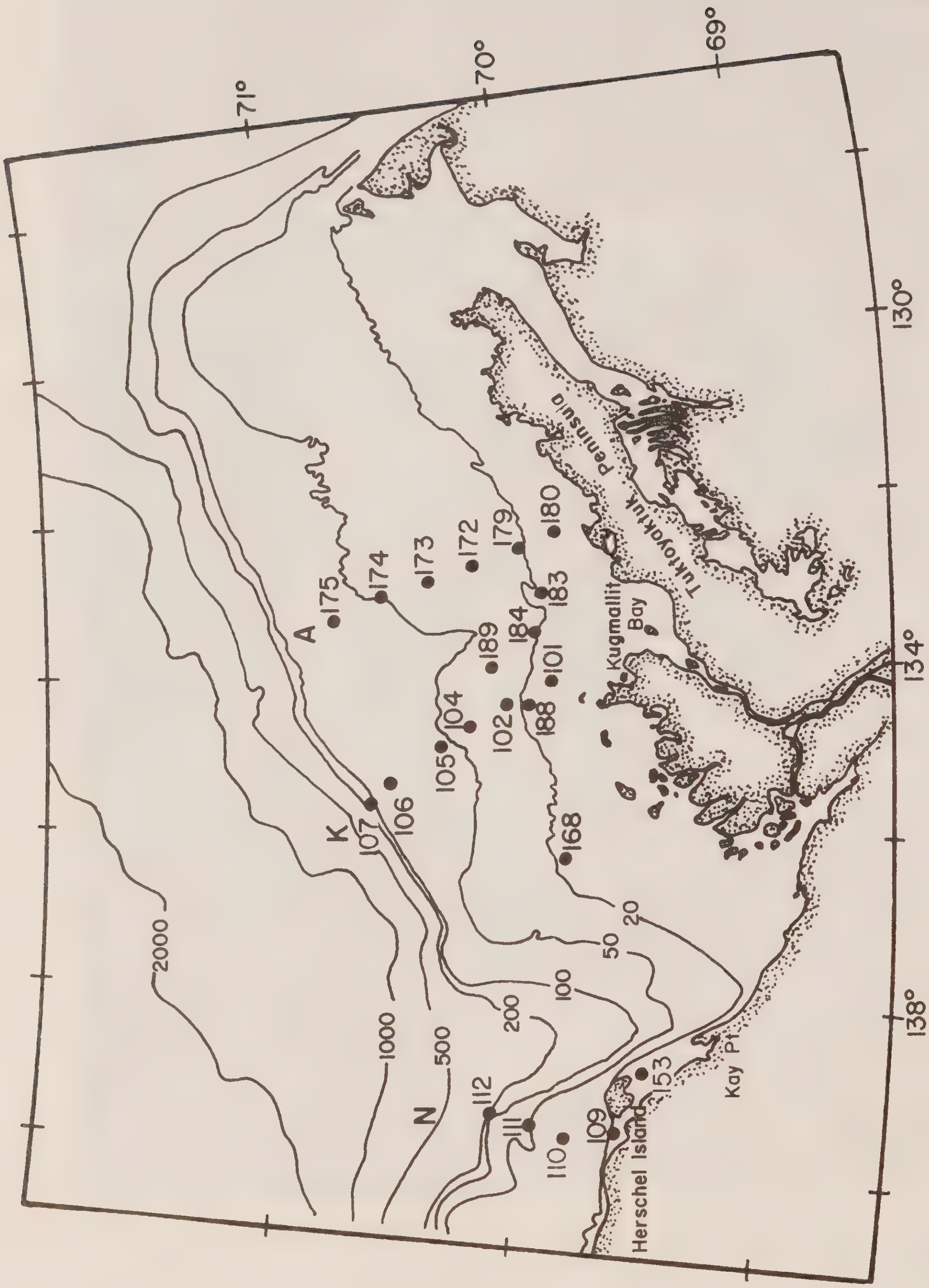

71°
70°
69°
130°
134°
138°
Tuktoyaktuk Peninsula
Kugmallit Bay
Kay Pt
Herschel Island
A
K
N
175
174
173
172
179
180
183
184
189
101
104
102
188
105
106
107
168
112
111
110
109
153
2000
1000
500
200
100
50
20

Figure 41

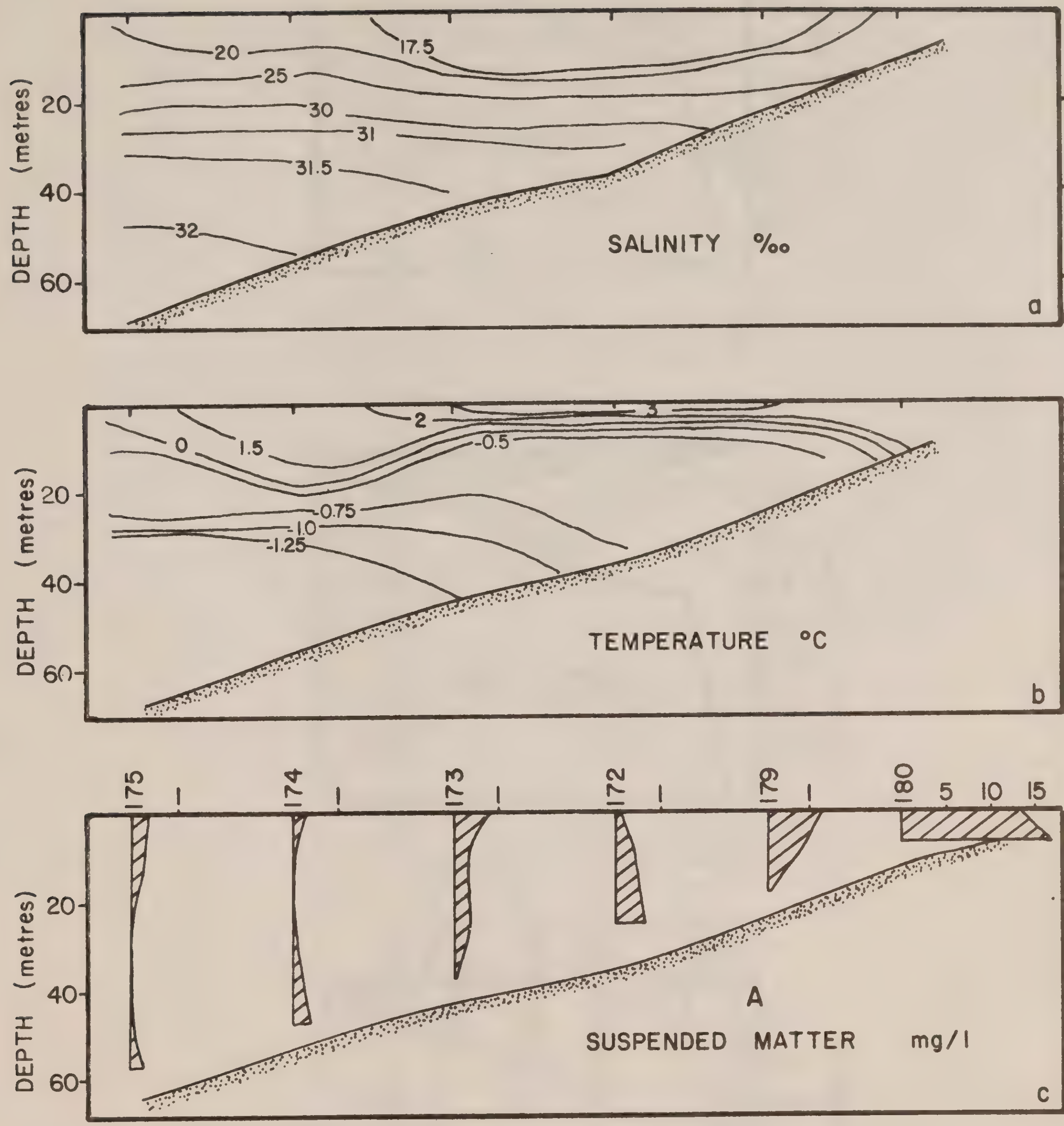

DEPTH (metres)
20
40
60
20
17.5
25
30
31
31.5
32
SALINITY ‰
a
DEPTH (metres)
20
40
60
2
3
0
1.5
-0.5
-0.75
-1.0
-1.25
TEMPERATURE °C
b
175
1
174
1
173
1
172
1
179
1
180
5
10
15
DEPTH (metres)
20
40
60
A
SUSPENDED MATTER mg/l
c

Figure 42

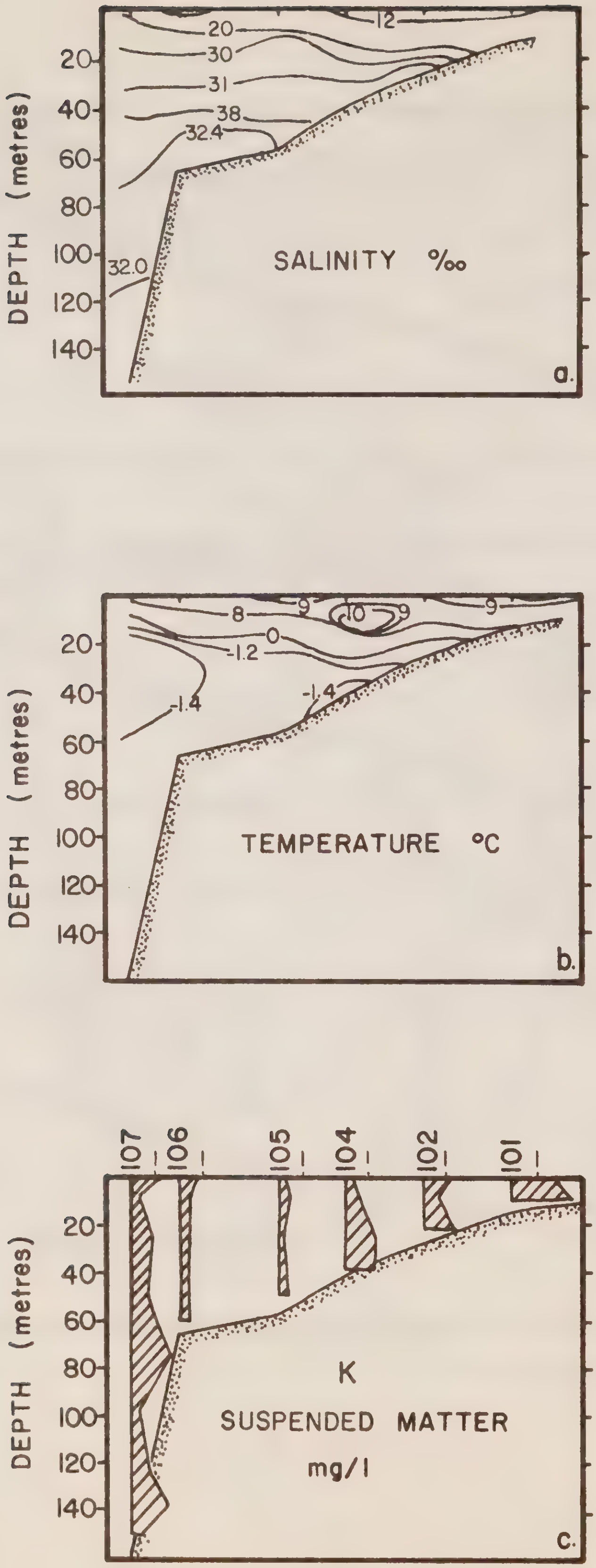

DEPTH (metres)
20
40
60
80
100
120
140
12
20
30
31
38
32.4
32.0
SALINITY ‰
a.
DEPTH (metres)
8
9
10
9
9
0
-1.2
-1.4
-1.4
TEMPERATURE °C
b.
107
106
105
104
102
101
DEPTH (metres)
K
SUSPENDED MATTER
mg/l
c.

Figure 43

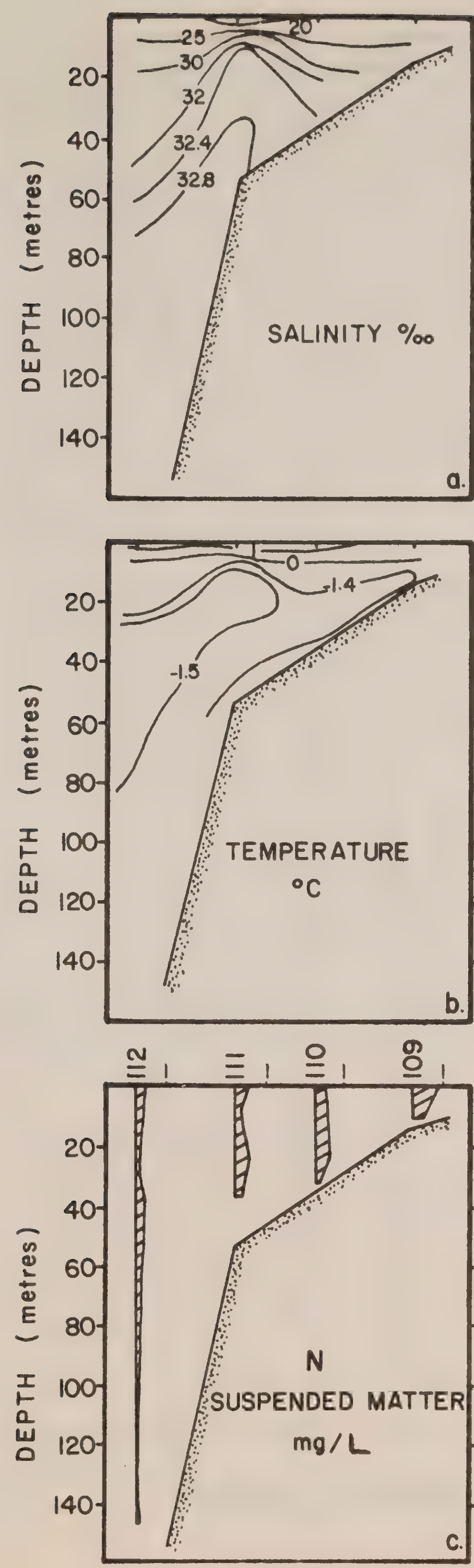

DEPTH (metres)
20
40
60
80
100
120
140
25
20
30
32
32.4
32.8
SALINITY ‰
a.
0
-1.4
-1.5
TEMPERATURE
°C
b.
112
111
110
109
N
SUSPENDED MATTER
mg/L
c.

Figure 44

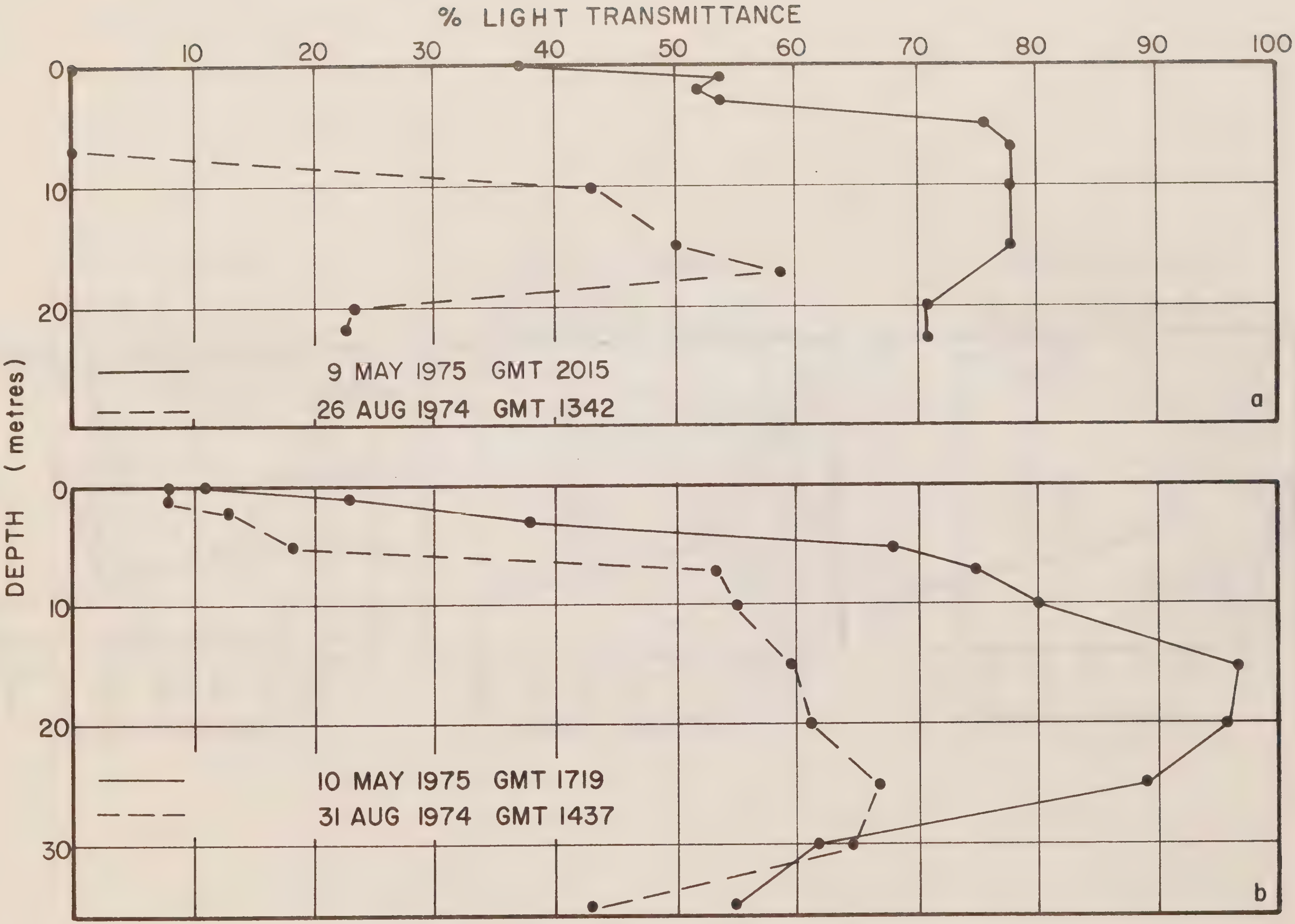

% LIGHT TRANSMITTANCE
DEPTH (metres)
9 MAY 1975 GMT 2015
26 AUG 1974 GMT 1342
a
10 MAY 1975 GMT 1719
31 AUG 1974 GMT 1437
b

Figure 45

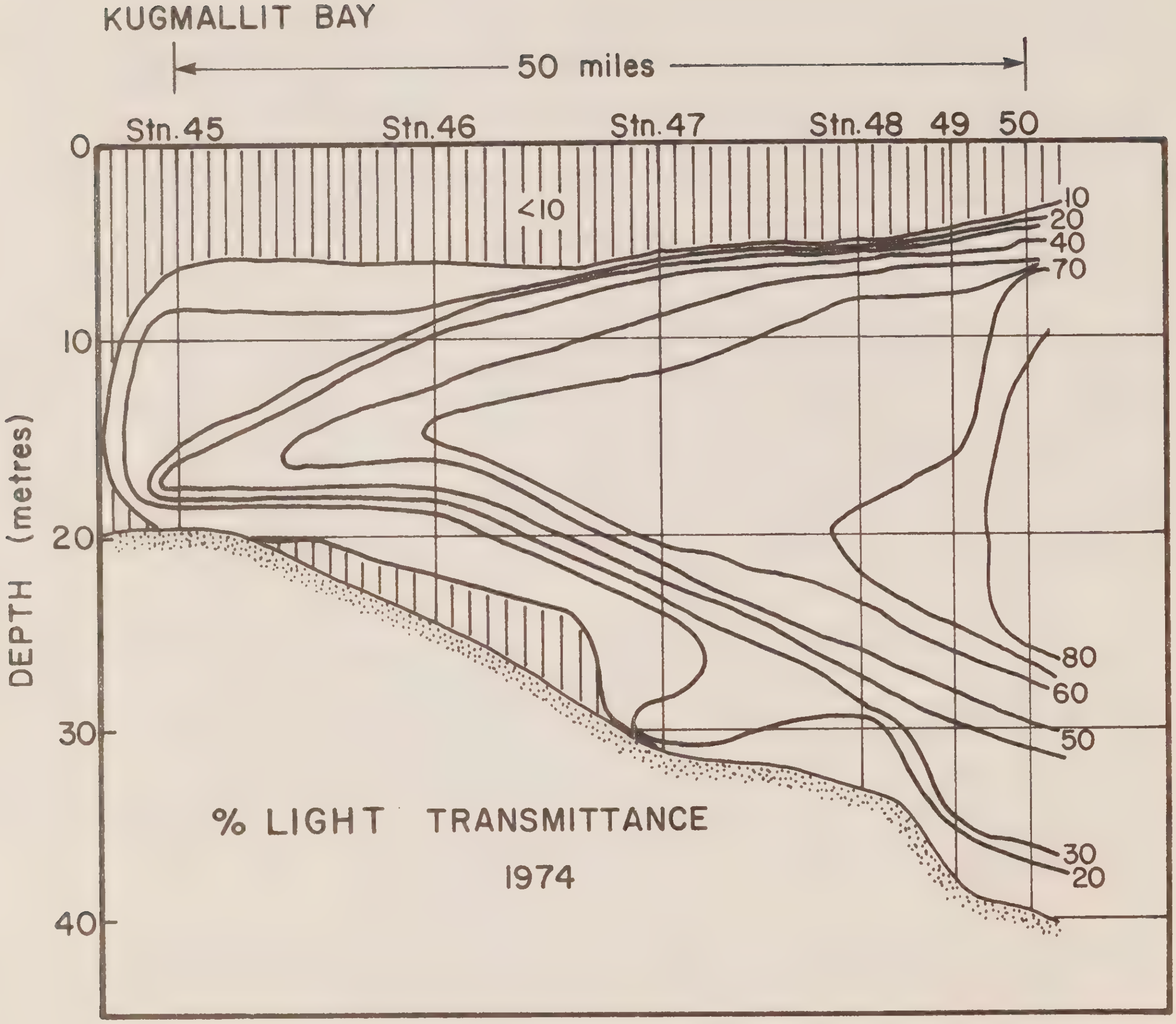
mouth of the Mackenzie Canyon and one along the axis of the Canyon (Figures 46 and 47). Both spring and summer profiles indicate the presence of a thin surface layer, generally less than about 10 m thick, of high turbidity. Below this layer, the turbidity decreases sharply with depth to a minimum, the water becoming quite clear between about 10 m to 20 m. Those depth intervals associated with large and rapidly-decreasing values appear to correspond approximately to those of the low-salinity surface layer and the halocline (or thermocline) respectively. These admittedly-isolated instances appear to differ from other findings in which no ambiguous relationship was observed between turbid and surface layers; therefore, the agreement may be fortuitous. The relative clarity of the mid-depth layer was believed to signify the onshore flow of relatively clear water as replacement for water lost by entrainment to the surface waters (the estuarine mechanism). A significant increase in turbidity was encountered near the bottom.

The presence of the surface turbid layer in summer also is evident in the cross sections associated with the transects. Away from the Mackenzie Canyon it appears that layers at mid-depth are clearer than those at the bottom and at the surface: the clarity appears to increase to seaward. No mid-depth maximum in turbidity was discernible at the time of monitoring, in contrast with conditions noted in Figure 42. In the Canyon the surface turbid layer was underlaid by water whose clarity increased with depth.

The major components of the suspended matter include: fine inorganic (mineral) particles less than about 5 μm in size; organic aggregates of mineral particles and plankton (100-400 μm in size); dense red-brown aggregates of particles, generally 40-100 μm in size and primarily containing iron in various phases and plankton, principally diatoms and silico-flagellates. No clearly-defined horizontal distribution patterns were apparent for the major components.

The suspended minerals present (illite (I), montmorillonite (M), kaolinite (K) and chlorite (C)) show a general agreement with the average composition of Mackenzie River sediments. Illite is the dominant clay mineral throughout the area and displays no apparent distributional trends. The remaining clays, on the other hand, display distinct differences in distribution, at least within the area studied. Waters in Mackenzie Bay and on the shelf of the Delta contain M and K, but little C. The near shore waters northeast of Kugmallit Bay - the eastern distributary of the Mackenzie River - are featured by abundant C but no M or K.

The mid-water maxima in suspended-material concentration sometimes observed are generally attributed to a depth-localized



KUGMALLIT BAY
50 miles
Stn. 45
Stn. 46
Stn. 47
Stn. 48
49
50
0
10
20
30
40
DEPTH (metres)
<10
10
20
40
70
80
60
50
30
20
% LIGHT TRANSMITTANCE
1974

Figure 46

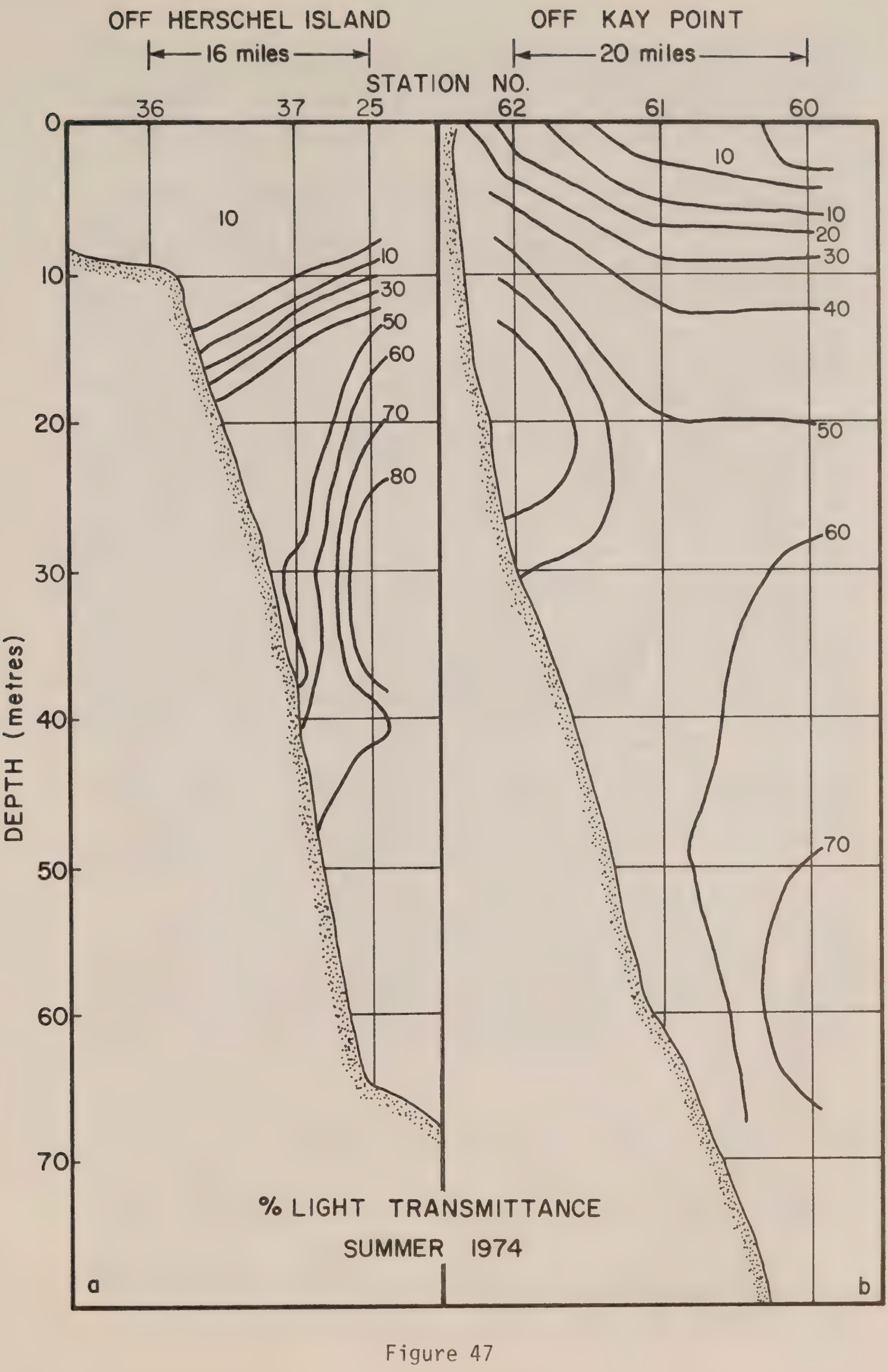

OFF HERSCHEL ISLAND
16 miles
OFF KAY POINT
20 miles
STATION NO.
36
37
25
62
61
60
0
10
20
30
40
50
60
70
DEPTH (metres)
10
10
30
50
60
70
80
10
10
20
30
40
50
60
70
% LIGHT TRANSMITTANCE
SUMMER 1974
a
b

Figure 47

slowing in the rate of particle settling below the surface layers. However, no definite relationship is as yet apparent between these maxima and the position of the halocline or thermocline (and the associated water density increase with depth).

The appreciable near-bottom maxima indicated in both the suspended-material and light-transmission measurements are also uncertain as to origin. The concentrations of suspended material found are indicated to be too small for turbidity currents to be considered as a primary agent for the generation of such maxima, although such currents may be of significance in isolated instances. Other generating mechanisms originally believed worthy of consideration are tidal and non-tidal (near)bottom currents, surface waves and breaking internal waves. Each of these possibilities has been indicated to bring about notable bottom-turbidity maxima in at least one area other than that being discussed here. However, of these only the bottom currents have been sufficiently studied for one to offer informed comment upon their capability of generating such maxima in the Beaufort Shelf area itself. The findings of these studies are noted in some detail in Section 4.2.2.2; however, some of the results may be anticipated here. It appears that tidal currents at the bottom are much too small (generally 2-3 cm/sec) to bring into suspension (erode) any of the principal size classes of minerogenic material - clay, silt and sand - found on the shelf. Typical non-tidal speeds, as denoted by residual values, were found to be no more than about 8 cm/sec. Such speeds, usually directed north-eastward, are also insufficient to bring shelf material into suspension. Maximum values encountered were about 40 cm/sec, although those at most localities ranged between 15 and 25 cm/sec. These speeds are sufficient to erode and transport sand sized material (0.062 to 2.00 mm), but not material either larger or smaller. It is suggested, therefore, on the basis of presently available data, that erosion and transportation of surficial shelf materials in the area of interest by bottom currents (tidal or non-tidal acting singly or in concert) cannot be a prevalent feature. As for the remainder of the possible factors suggested above, more study is needed to evaluate their role in producing bottom turbidity maxima. During periods of ice cover, however, tidal and persistent unidirectional currents may become the only possible causes of bottom turbidity maxima on the Beaufort Shelf.

4.2 Circulation

4.2.1 General Circulation in the Arctic Ocean

Water circulation, primarily that in the horizontal, is probably the most important oceanographic characteristic of the Beaufort Sea in the present context.

Surface currents are of prime significance in the transport of oil or other pollutants which can remain at or near the air-water interface for a considerable time. Water movements at depth

can be of possible importance in several different aspects such as: the transportation of oil which has become distributed throughout the water column; and the scouring of bottom deposits which may jeopardize the stability and safety of structures, such as oil-rig complexes, seated on the bottom.

The contribution of the water circulation to the movement of ice must also be recognized. The transportation of all forms of ice has important implications to the safety of drill-ship operations, to the applicability and effectiveness of oil spill countermeasures, and to the feasibility and degree of sea-borne commerce in the Beaufort Sea.

Water movements in the Beaufort Sea generally are generated by a complex of primary influences, including wind stress (a function both of wind and of ice-cover extent), tides, fresh water inflow and atmospheric pressure gradients. Once in existence by whatever cause, such motions can be modified by one or more secondary factors such as bottom topography, lateral boundaries, Coriolis and centrifugal forces and, again, the degree of ice cover.

In this section, the general horizontal circulation characterizing the Beaufort Sea proper is briefly discussed. Details of this circulation are obscure. It may be noted that the interplay between the various factors noted above can be more clearly (although by no means completely) demonstrated throughout the continental shelf area at the southern boundary of the sea (Section 4.2.2).

It should also be emphasized that at present the characteristics of the general fields of motion in the Beaufort Sea (as well as in the Arctic Ocean as a whole) are much less well known than are the properties of the various water masses.

The pack ice of the Arctic Ocean is in continuous motion. The general drift of surface waters is believed to be northward across the Pole then out of the Arctic Ocean and along the eastern side of Greenland: as determined, for example, by movement of driftwood of known origin and of relicts from vessels crushed by the pack ice, as well as by recorded movements of ice islands, and ships imprisoned in the ice. The paths followed by several manned ice islands are indicated in Figure 48. Offshore of the continental shelf in the Beaufort Sea the motion of the Arctic water mass is dominated by the Beaufort Sea Gyre, a secondary feature of the overall Arctic circulation. This gyre is centered approximately at 77°N, 145°W. The motion in the gyre is clockwise and the movement off the western Canadian Arctic coast and Alaska is, therefore, westerly. Water undergoing this motion merges with the general transpolar stream north of the Chukchi Sea. Mean speeds are estimated on the basis of ice-island movement, to be about 2 to 4 cm/sec (1.7 to 3.5 km/day); values of up to

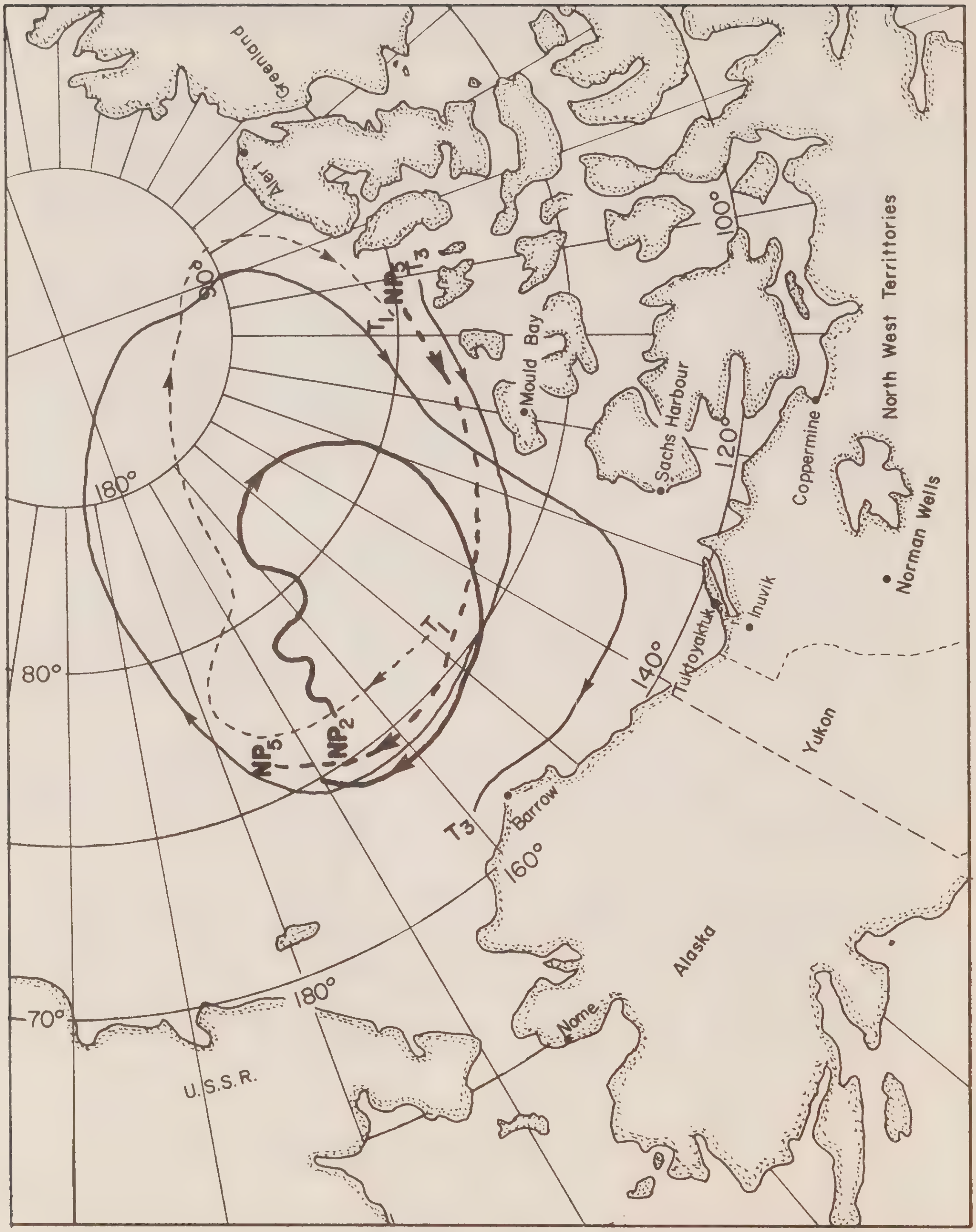

Greenland
Alert
90°
T_1
NP_3
T_3
Mould Bay
100°
Sachs Harbour
120°
Coppermine
North West Territories
Norman Wells
Inuvik
Tuktoyaktuk
140°
Yukon
180°
80°
T_1
NP_2
NP_5
T3
Barrow
160°
Alaska
180°
70°
Nome
U.S.S.R.

Figure 48

20 cm/sec or more (> 17 km/day) have been recorded occasionally for periods up to a few days. There remains the question of how closely the observed drift of pack ice or ice islands represents the actual general shallow movement within the Arctic water mass. The problem has not yet been completely resolved. However, there are believed to be significant differences between the drift of pack ice as a whole and that of individual ice islands. Islands have greater draft than does pack ice, in general; as a result, they appear to be influenced more by the actual water motion than by wind. Wind is believed more significant in the case of pack ice. The variability in the day-to-day drift of the islands causes their paths to be fairly erratic in detail. Only when averaged over appreciable periods (several weeks or more) are the motions of ice and water found to be similar.

An interesting feature has been noted in the circulation at depths between about 100 and 200 m in the vicinity of the boundary between the Arctic and Atlantic water masses. Eddies of appreciable horizontal size ($\sim$ 10 km) are indicated to occur. Maximum speeds of up to 30 to 40 cm/sec have been associated with these features. Whether similar motions occur at greater depths is as yet unknown. The speeds at a location have been found to grow and decay over the course of a few days, presumably coincident with the passage of such an eddy.

The circulation at depth - that associated with the Atlantic and bottom water masses - is not nearly as well known as is that of the Arctic mass. What is known has been deduced primarily from temperature and salinity distributions, although the results of recent direct current measurements have also been utilized. The Atlantic mass, after entering from the Greenland Sea, appears in general to move eastward along the Eurasian continental slope into the basin underlying the Beaufort Sea. North of Alaska there may be a small clockwise gyre. The flow exits eastward north of Ellesmere Island and Greenland. The mean speed is believed to be less than 3 cm/sec (2.5 km/day). The very few deep-current measurements so far taken indicate that the velocities in the bottom water are very similar to those characterizing the overlying Atlantic mass. It appears that these two deeper masses may be moving as a unit. Tidal influence appears to be negligible. There exists the possibility that deep currents (those below about 500 m) may experience significant perturbations because of the effect of transient atmospheric pressure systems.

4.2.2 Circulation Over the Continental Shelf of the Beaufort Sea

4.2.2.1 Surface Circulation

Factors Influencing the Circulation

While the surface movement of water overlying the Beaufort continental shelf is by no means thoroughly known, several basic features

have been determined. Over the Alaskan portion of the shelf a variety of observations, although scattered in both time and space, suggest that in summer the surface waters generally flow westward at speeds less than about 15 cm/sec. The strongest prevalent currents in this area appear to occur near Point Barrow ($\sim$ 20 cm/sec).

These movements apparently result basically from the general wind régime. The current direction normally falls within the same quadrant as does the wind direction (predominantly to the west) unless wind speeds are less than about 7 km/h. At these lower wind speeds the current direction varies, being westward on some occasions and eastward on others. The currents are, however, subject to substantial spatial and temporal (day-to-day at least) variability.

In the southeastern Beaufort Sea, the results of early studies suggested that the surface-current régime in summer is primarily the result of two factors: winds, and fresh water run-off from the Mackenzie River. Currents between the surface and 2-3 m depth were fairly intensively studied - primarily off the Mackenzie Delta and the Tuktoyaktuk Peninsula to about 71°N - during the summers of 1974 and 1975. Several general results have been either confirmed or discovered during these later studies. The findings will therefore be described in some detail.

It has been found important to recognize that a number of processes are involved, none of which is completely understood even in situations much simpler than the present one. The large-scale variability of the surface currents is primarily determined by the action of the wind. However, the current pattern produced by the wind is affected by the Mackenzie River outflow - both indirectly (by its influence on the density structure) and directly (by the current pattern associated with the outflow itself). Both these patterns are in turn affected on a smaller scale by eddies arising either from instabilities along the frontal zone between the Mackenzie River water and the receiving sea water or from interactions between the flow and the topography.

The flow component having the largest time scale is that associated with the river outflow.

The dynamics in this case deal with a river flowing perpendicularly to a vertical straight coast into a deep ocean. Several forces are involved. The Coriolis force tends to turn the river flow to the right (east) along the coast. This force is balanced initially by the centrifugal force associated with the curvature of the turning flow, and latterly by the pressure gradients. These gradients are associated with the horizontal variations in the mean density of the water column, which result from the mixing of fresh and salt water. For the Mackenzie River, this should lead to a slow broad eastward flow parallel to the coast. In considering the river outflow, it is important to recognize that it will be accompanied by an inflow of the underlying, more saline, ocean water to replace that carried away by mixing with the outflowing fresh water. Such outflow and inflow represent the essential elements of the "positive estuarine" circulation which already has been noted.

The component of the flow with the largest horizontal scale is probably the wind-driven motion in the near-surface water. However, the vertical scale of this motion is essentially limited to the layer above the large density gradient, as this gradient will suppress the vertical component of turbulence and hence vertical momentum transfer. According to modern ideas, there are two significant time scales. The longer one is represented by the scale of the variations in the wind, while the shorter is represented by the "inertial period" - 12 hours 46 minutes at 70°N (see page 123).

Consider the case in which a coast line is located on the right-hand side of an observer looking downwind - as will occur for a west wind in the Beaufort Sea. According to the theory of boundary currents, transport to the right of the wind will move water towards the shore resulting in the build-up of a pressure field. This field produces a downwind flow parallel to the coast. In the case where the coast is found to the left of the wind direction, as for an east wind in the Beaufort Sea, the net transport is away from the coast resulting in upwelling of deeper water near the shore to replace fluid transported away.

Surface-Current Characteristics During Various Wind Régimes

The wind having the greatest effect on the currents in the southeastern Beaufort Sea is that from the northwest, especially during storms, at which times speeds can rise to over 35 km/h for extended periods. Such winds usually are generated by a low pressure centre passing across the northern Beaufort Sea from west to east. A period of several days of calms or of light winds often follows such a storm. The other strong steady winds that have been observed are easterly or northeasterly in direction and accompany the passage of a high pressure disturbance. The surface currents generally accompanying each of these three wind régimes can be characterized at some length. (It should be noted that the direction assigned to an ocean current is that in which the current is moving whereas that associated with a wind is that from which the wind is blowing.)

Strong Northwest Winds (Figure 49)

During NW winds of 35 km/h or more, the water movement offshore is southeast toward the coast, 30^{o} to the right of the wind, at 35 cm/sec (which is about 3% of the wind speed). The maximum southeasterly drift speed which has been recorded during a northwest wind is almost 50 cm/sec. This would correspond to a travel of between 40 and 50 km/day. Near the shore, within about 10 km of the coast, the current is parallel to the shore and moves to the northeast with a speed that ranges from 25 cm/sec north of Pelly Island to 50 cm/sec north of Atkinson Point and Cape Dalhousie. The maximum longshore drift that has been observed is 75 cm/sec north of Cape Dalhousie.

Under such weather conditions, a clockwise circulation around Liverpool Bay probably exists. A very strong current flows around the tip of Baillie Islands and down the eastern coast of the Bathurst Peninsula. There appears to be a counter-clockwise circulation into Kugmallit Bay, with the river water from the east channel of the Mackenzie moving off to the east out of the bay, and the river water from Mackenzie Bay flowing around Richards Island into Kugmallit Bay from the west. During northwest winds, the Mackenzie River plume can be seen from the air as a very

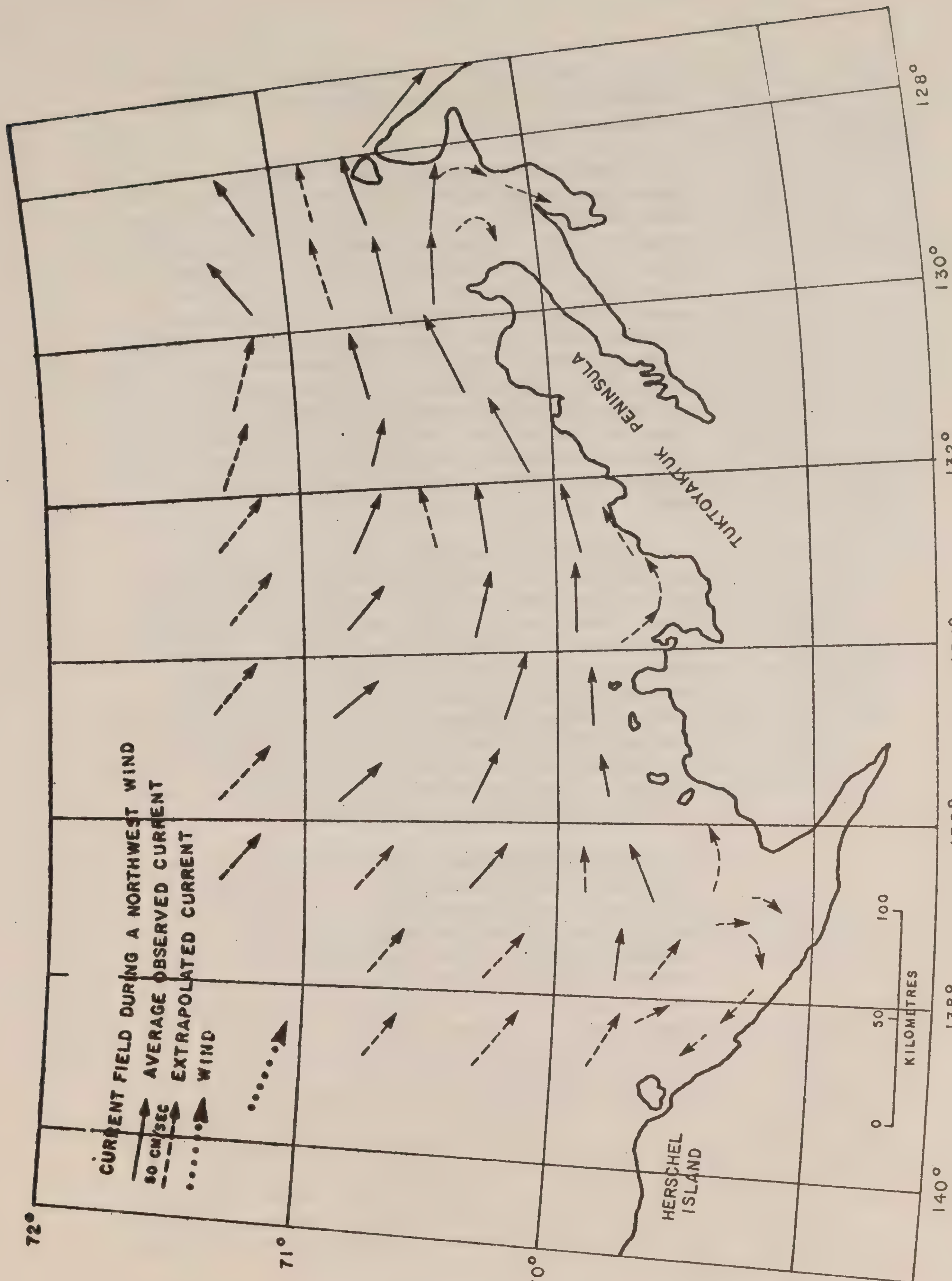

CURRENT FIELD DURING A NORTHWEST WIND
50 CM/SEC
AVERAGE OBSERVED CURRENT
EXTRAPOLATED CURRENT
WIND
TUKTOYAKTUK
PENINSULA
HERSCHEL ISLAND
KILOMETRES
0
50
100
72°
71°
70°
69°
128°
130°
132°
134°
136°
138°
140°

Figure 49

well defined silty strip hugging the coast and indicating the prevailing direction of water movement.

Due to the lack of data in Mackenzie Bay during northwest winds, the current field in this area has not been well defined. Northwest winds blowing along the western shore of Mackenzie Bay should cause a longshore current in the same direction as the wind. The result would be a counterclockwise circulation in Mackenzie Bay, with a southeasterly longshore current along the western shore. Ships' drift measurements as well as airborne observations of ice accumulations and sediment-laden water suggest, however, that a small clockwise gyre is set up in Mackenzie Bay during northwest winds, causing a northwesterly longshore current along the western shore of the bay.

Insufficient data are available from the western part of the bay either to confirm or refute this speculation, although a few observations indicate such a current having a speed of < 10 cm/sec. A definite northwesterly current of 10 cm/sec occurs off Stokes Point after a northwest storm or during light south or east winds. Water movement in the southwest corner of the bay off Shingle Point appears to be quite random most of the time, probably due both to the presence of Mackenzie River eddies and the geographic configuration of the bay.

The time-dependent aspect of the current field can also be considered. As a northwest wind begins to blow, an onshore current develops moving slightly to the right of the wind. The response of the current to the wind will depend somewhat upon the initial speed of the water. Bottom currents at three locations in the Beaufort Sea suggest a six-to-eight hour lag behind the wind but the surface current response time is probably substantially shorter. The onshore current increases with an increase in wind speed. It builds water up against the coast, causing a longshore current toward the northeast. This movement would increase and reach a steady state within six to eight hours after the onset of the wind. This is also the response time of the water height on the shore. The speed of the

longshore current varies directly with wind speed. The lateral extent of the current appears to increase with time to a maximum distance of 50 km offshore north of Atkinson Point and Cape Dalhousie. The position of the current "core," in which the maximum along-stream speed occurs, can be represented by a line from 70°N, 133°W to just north of Baillie Islands; the core is therefore approximately 10 km offshore.

Some theoretical work has been done on the generation of longshore currents by a wind stress perpendicular to the coast line. One result which has been derived indicates that the build up of a longshore current takes from three to eight hours, depending both on the water depth and current speed (which is assumed to be approximately 3% of the wind speed). The data obtained in 1974 and 1975 therefore appear to agree with the theory.

In the case of strong west winds of several days' duration, the winds often swing from southwest to west and then to the northwest. The response of the water to the west and southwest winds, while difficult to determine in detail, is undoubtedly similar to the response to a northwest wind. If the wind is more southwesterly, there is likely to be more of a longshore component in the drift and less of an onshore component. The circulation in Mackenzie Bay would be clockwise, with a longshore current flowing southeast along the western shore of the bay.

Following a Northwest Wind (Figure 50)

A characteristic drift pattern occurs subsequent to the relaxation of a strong northwest wind that has caused an increase in water height along the coast.

After the wind has ceased, the longshore current north of Tuktoyaktuk Peninsula continues to exist for at least two or three days until it decays due to frictional dissipation. In August 1975, the longshore current north of Tuktoyaktuk Peninsula was still 75% of the steady-state value 48 hours after the relaxation of the generally strong northwest wind. However, during the third and fourth days, the current actually reversed direction north of Atkinson Point and at 70°30'N was, during this time, reduced to 20% of

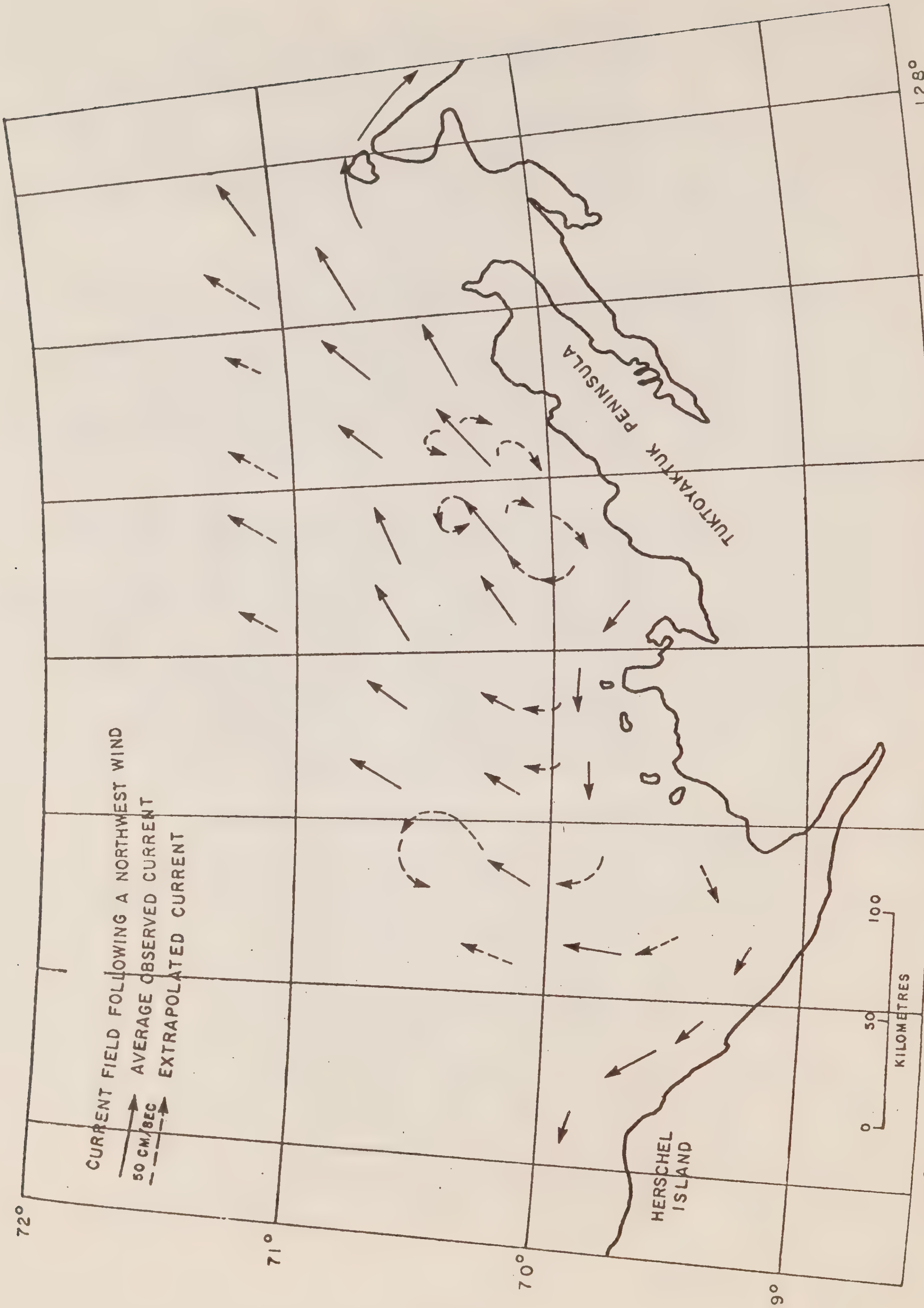

CURRENT FIELD FOLLOWING A NORTHWEST WIND
50 CM/SEC
AVERAGE OBSERVED CURRENT
EXTRAPOLATED CURRENT
TUKTOYAKTUK PENINSULA
HERSCHEL ISLAND
0
50
100
KILOMETRES
128°
130°
132°
134°
136°
138°
140°
72°
71°
70°
69°

Figure 50

its steady-state speed during the accompanying storm surge (page 131). A fast current (75 cm/sec) continued to flow southward along the eastern coast of Cape Bathurst.

After a northwest wind, water also flows out of Kugmallit and Mackenzie Bays toward the northwest at speeds of about 20 cm/sec and 40 cm/sec respectively, causing a westward current around Richards Island. This may have caused the current reversal noted above. As a result, a divergence is created in Mackenzie Bay and a convergence north of Richards Island. Large eddies in Mackenzie River water observed north of Richards Island may have been associated with this convergence. The divergence in Mackenzie Bay may result from both the presence of the Mackenzie Canyon and the V-shape of the isobaths in the bay. Just how much influence the wind exerts in determining the current field is difficult to assess.

Strong East Winds (Figure 51)

The effects of this wind régime may be summarized by consideration of the current field anticipated during steady east winds of speeds greater than about 25 km/h and of duration about 48 hours. This situation occurred only once in the summer of 1974 (early September), the east winds persisting for at least 10 days. A consistent current pattern was established. The field consisted of an offshore (northwestward) movement of speeds up to 75 cm/sec as well as a westward longshore current of about 35 cm/sec set up by the changed density distribution. Observations indicate that a sudden relaxation of the wind causes a relaxation of the current with 24 hours. In September 1975, a strong northeast wind produced a a similar general drift but with a more southwesterly trend of current off Tuktoyaktuk Peninsula.

There are frequent periods of light east winds lasting for 24 hours or less. Such winds appear to be instrumental in altering the already-existing current direction slightly or in causing large-scale eddies which distort the unidirectional current field , but they do not set up a uniform current pattern over the whole area in question.

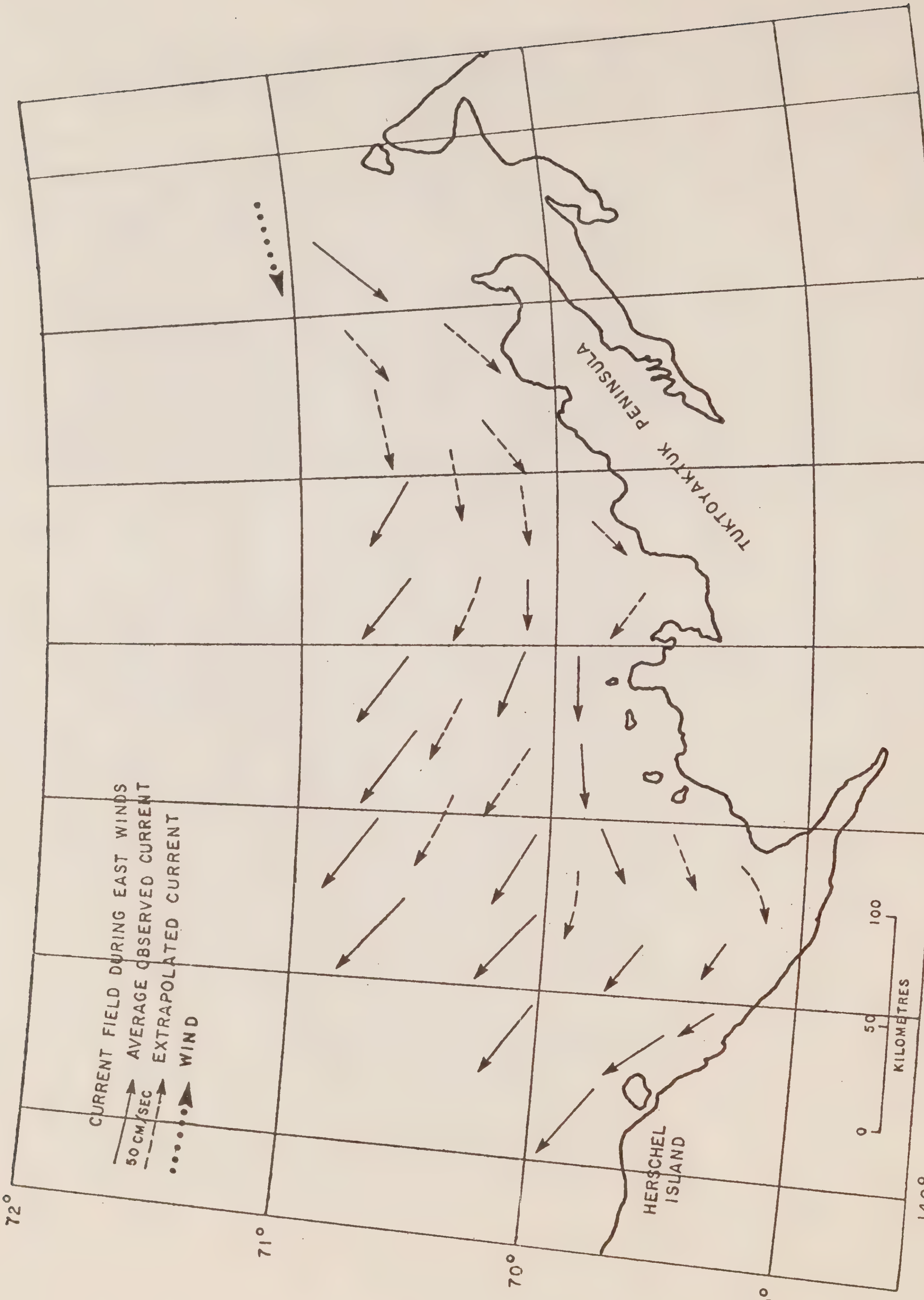

CURRENT FIELD DURING EAST WINDS
50 CM/SEC
AVERAGE OBSERVED CURRENT
EXTRAPOLATED CURRENT
WIND
TUKTOYAKTUK PENINSULA
HERSCHEL ISLAND
0
50
100
KILOMETRES
72°
71°
70°
69°
128°
130°
132°
134°
136°
138°
140°

Figure 51

Predictability of Surface-Current Conditions

During open-water conditions in the Beaufort Sea, the structure of the water (Figure 39) varies horizontally, especially because of the influence of the Mackenzie River outflow. In addition, winds are not uniform in time or space and the wind drift is not the only current. A major problem is the determination of what portion of the motion is reproducible and predictable, given information of the type likely to be available under practical circumstances.

Because of the obvious influence of the wind upon the surface motion, it is tempting to predict the surface drift on the basis of anticipated winds. However, it turns out that there is apparently no unambiguous relationship between the wind speed and the surface drift speed.

The relationship between wind and current direction is equally unrewarding. Even under winds of relatively uniform direction, the current directions can vary quite markedly. Thus, predictability of surface current characteristics from those of the wind is of a very low order.

One source which is believed to prevent predictability is the presence in the area in question of eddies which range in horizontal size from about 10 to 50 km. The most likely sources of these features are shear instabilities along the front between the Mackenzie River and the receiving sea water and/or interactions of the flow with topographic features.

The limit of prediction indicates only that there is a mean generalized response to the stronger wind fields. In any particular case, this response can be perturbed by additional random velocities only slightly smaller than those associated with the wind drifts.

Summary

The summer (open-water) surface currents in the southeastern Beaufort Sea south of 71^{0}N result from many contributing factors. One of the two dominant influences on the mean daily drift involves the major wind systems associated with the passage of large atmospheric pressure centres. Northwesterly winds are apparently the most impor-

tant, but easterlies also are of significance. The other is the Mackenzie River discharge. The effect of these two influences is strongly biased by the orientation of the coastal boundary features and moderated by such factors as local winds and eddies of various size. The variability associated with these latter features introduces a large and unpredictable random component into the surface currents. At the present time, therefore, forecasting of surface-current conditions in detail is generally ineffective.

The predominant surface-current direction appears to be to the northeast. An exception to this occurs off Herschel Island and Stokes Point; there the current is basically northwesterly. A persistent divergence appears to occur in Mackenzie Bay and convergence is frequently observed north of Richards Island.

4.2.2.2 Sub-surface Circulation over the Canadian Shelf

To this writing, the only significant amount of quantitative information available upon sub-surface water movements over the Canadian portion of the Beaufort Shelf is composed of the bottom-current data obtained during the Beaufort Sea Project. In this study, such currents were monitored at 15 locations on the shelf at, or onshore of, the 100 m isobath (Figure 52). Data were obtained every half hour at each station, primarily during the period August 1974 - August 1975, although a small amount was provided by one station during May and June 1974. It is to be noted that, in 1975, the extent of the polar pack ice cover within the area altered significantly during the course of the monitoring. It engulfed all stations but Nos. 10, 11 and 14 at the eastern end of the study area up to the 30th of May; northwesterly retreat successively exposed more stations until by the middle of July all were free of ice.

A brief summary of the information obtained upon various characteristics of the water movements (such as maximum and root-mean-square speeds and residual velocities) for the various stations and intervals providing a significant contribution is given in Table VII.

It may be noted that in this study the current speeds associated with tidal action are

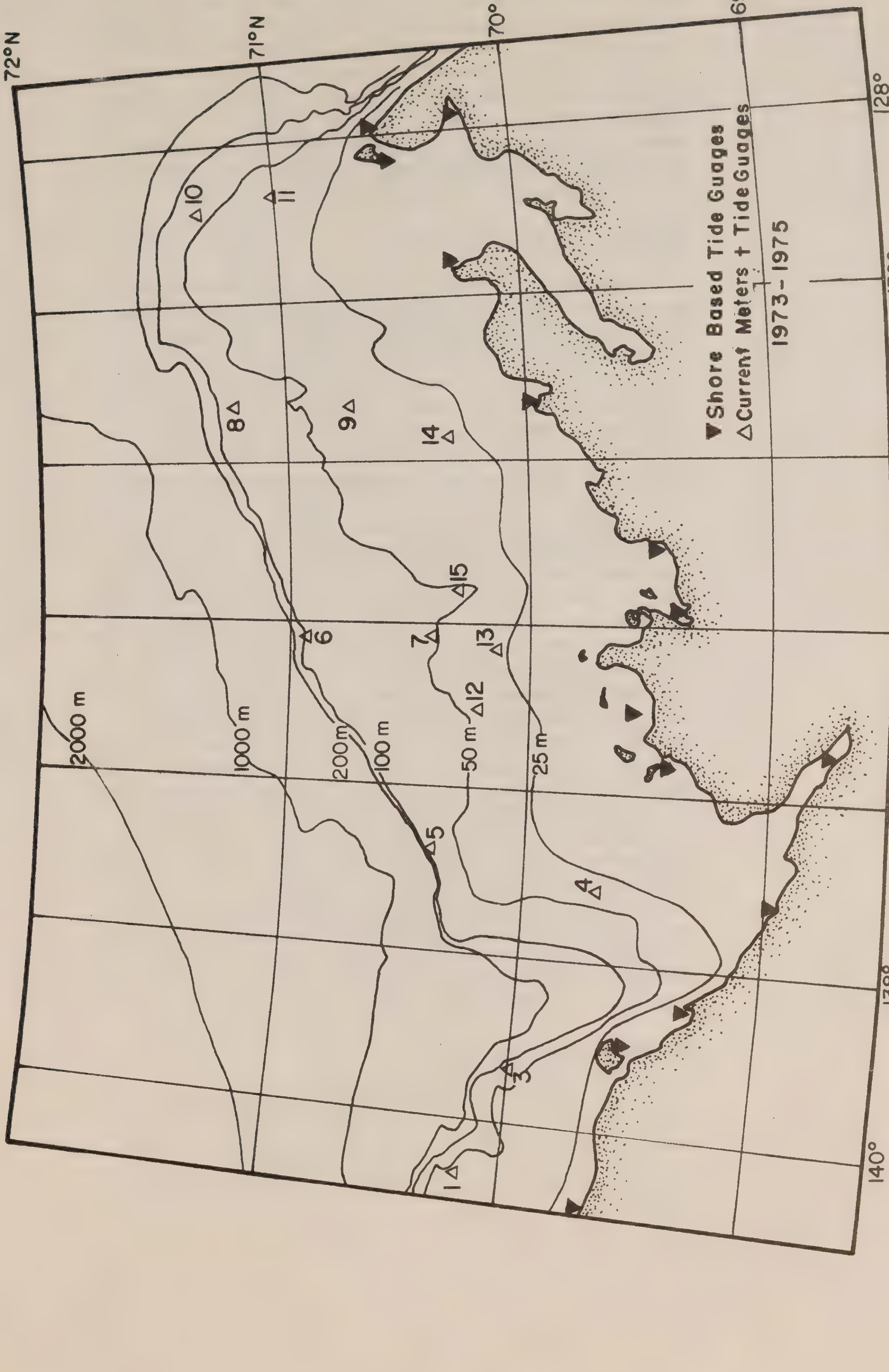

72°N
71°N
70°N
69°N
128°
130°
132°
134°
136°
138°
140°
2000 m
1000 m
200 m
100 m
50 m
25 m
▼ Shore Based Tide Guages
△ Current Meters + Tide Guages
1973-1975
1
3
4
5
6
7
8
9
10
11
12
13
14
15

Figure 52

found to be very weak, of the order of only 2 to 3 cm/sec. Consequently, tidal currents, especially the contributions having frequencies slower than diurnal, are in general strongly masked by movements arising from other causes. Details of the tidal currents are provided in Section 4.3. However, it should be remembered that these currents, in isolated instances, may contribute significantly to the régime of borizontal motion.

Bottom Current Directions

North of Liverpool Bay and off the eastern portion of the Tuktoyaktuk Peninsula, the bottom current over the shelf was found to be always northeasterly. This feature characterizes Stations 8 and 10, at which depths are between 25 and 50 m. It may be noted that the presence of ice cover at Stations 8 and 10 appears to result in little difference either in bottom current direction or in speed, with respect to open-water conditions.

To the west, at the two mid-shelf stations north of the Mackenzie Delta (13 and 15), there are considerable differences in current direction, with respect both to the more easterly stations and to each other. At station 13, the bottom current direction closely parallels that of the contemporary surface wind. At 15, however, the current is generally southerly when it is simultaneously westerly at 13. The difference may result from the characteristics of the bottom topography in the vicinity of 15. At the edge of the shelf north of Mackenzie Bay (Station 5), the flow is again generally to the northeast. However, during the ice-free period, there are occasional instances when a change in the wind stress produces a marked change in direction. After a storm the currents at times become clockwise rotary, a condition believed due to the presence of inertial currents (page 123). At Station 4, a mid-shelf location off Mackenzie Bay, the current is generally northeasterly.

Bottom Current Speeds

The maximum speeds recorded in Table VII are seen to range from about 16 to 41 cm/sec, with most being between about 15 and 25 cm/sec. The 41 cm/sec value was recorded at Station 5 during a major storm in August 1975; the area was ice free.

TABLE VII

Station	Date	R.M.S. Speed (cm/sec)	Maximum Speed (cm/sec)	Average Residual Velocity	
				Speed (cm/sec)	Direction (°T)
4	9/5-30/6 74	3.6	23.1	2.4	043
13	26/4-29/7 75	5.6	20.2	0.5	159
15	28/4-5/8 75	7.5	21.6	2.2	134
9	26/4-5/8 75	6.0	21.0	4.4	054
11	25/4-4/8 75	9.9	38.1	8.2	040
5	29/4-2/8 75	8.0	23.1	6.0	047
8	26/4-4/8 75	6.2	16.3	4.9	032
10	25/4-4/8 75	5.8	16.4	4.9	035
13	6/8-8/9 75	6.4	23.8	0.9	110
5	3/8-10/9 75	13.8	40.9	8.3	051

A maximum speed of comparable value, about 38 cm/sec, was recorded at Station 11 near the end of May 1975 off Liverpool Bay, during a storm apparently somewhat less intense than the one noted immediately above; polar pack ice was still present nearby.

The RMS (root-mean-square) speed for each period indicated in Table VII is defined as follows. The mean square of the total number of speed values obtained during the period (the average of the squares of these values) is calculated. The RMS is the positive square root of this current, without regard to the direction. (The contribution of the tidal streams has not been removed from any of the individual speed values.)

The RMS speeds recorded during 1975 at several stations (8, 9, 11 and 13) were approximately 6 cm/sec for that portion of the recording interval preceding August. During August itself, the value rose to about 14 cm/sec because of the effects of two major storms during the month. Apart from this storm induced value, the greatest speed recorded was about 10 cm/sec, at Station 11. This value was significantly greater than others recorded during 1975.

The RMS value recorded at Station 4 (the sole location successfully monitored in 1974) was 3.6 cm/sec over a 52-day period. This was much smaller than any value found during 1975. It may be noted that the maximum speed of about 23 cm/sec recorded at 4 was equal to or greater than most occurring during the monitoring period in 1975.

The residual speed associated with any single current value is the speed remaining after subtraction of any speeds associated with significant components of the tide. The average residual velocity (speed and direction) associated with the stations and periods involved, clearly reveals the northeasterly flow prevailing in the eastern and western portions of the shelf area under study, especially the former (Figure 53). Residual velocities at Stations 4, 5, 8, 9, 10 and 11 all had directions lying around 32° and 54°T. The average speeds at 8, 9 and 10 were all between 4 and 5 cm/sec. Speeds at Stations 5 and 11 were larger. All the stations averaged about 8 cm/sec over a period of more than four months. Station 5

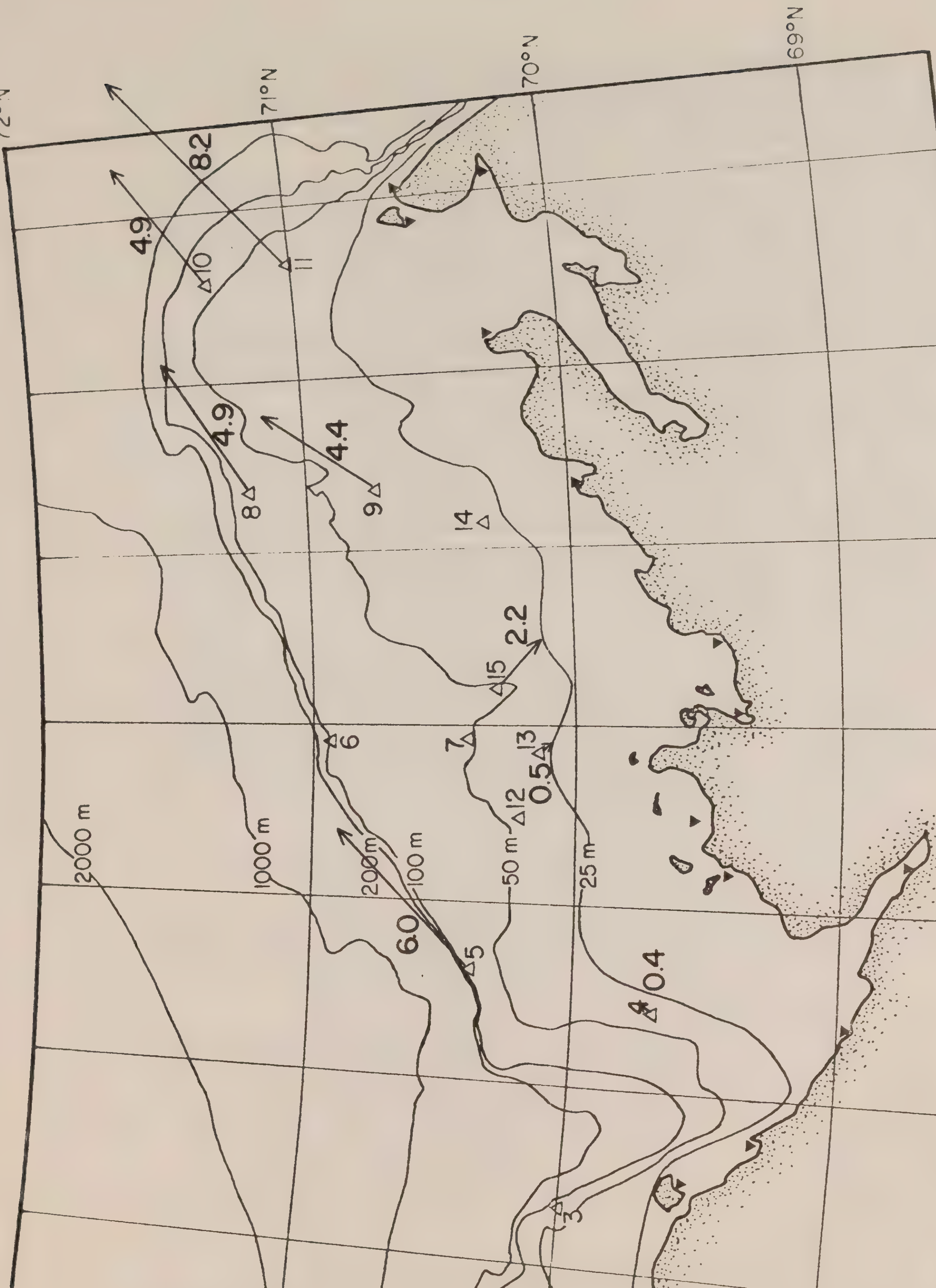

72°N
71°N
70°N
69°N
128°
130°
132°
134°
136°
138°
140°
2000 m
1000 m
200 m
100 m
50 m
25 m
8.2
4.9
4.9
4.4
2.2
6.0
0.5
0.4
1
3
5
6
7
8
9
10
11
12
13
14
15

Figure 53

possessed values of about 6 cm/sec prior to August; however, the two large storms in August again provided a significantly greater value (more than 8 cm/sec) during that month.

The stations in the middle of the area, 13 and 15, had their residual currents directed southeasterly (between about 134° and 152°T). Speeds were small: 2.4 cm/sec at 4 and 0.5 cm/sec at 13.

No definite explanation is as yet available, for the northeasterly trend which characterizes the bottom current present over the deeper and easterly portions of the shelf area studied.

Some General Relationships Between Winds and Bottom Currents

Several general features that suggest themselves from the study of bottom-current data obtained over the Canadian Beaufort shelf can be noted, briefly.

1) Throughout the eastern portion of the study area, the bottom current is always northeasterly regardless of the direction of the overlying wind. However, increases in wind speed associated with any direction are always accompanied by changes in the speed (magnitude) of the bottom current.

2) Throughout the remainder of the study area:

   a) For winds of speed less than about 27 km/h, no significant correlation is found between changes in wind speed and those in the bottom current.

   b) In the case of winds of speed between about 27 and 45 km/h, the influence of the wind upon the bottom current is at times noticeable, especially in the shallower inshore areas (e.g. Stations 13 and 15). However, no consistent or reliable relationship between wind and current was evident.

   c) For wind speeds greater than 45 km/h, several relationships can be inferred at two of the current-monitoring locations at least. At Stations 5 and 13, fluctuations

in current velocity correlate to some degree with this associated with these winds. It appears that winds blowing for a sustained period (2-3 days or more) from one direction are more likely to generate larger increases in current than are stronger winds of shorter duration. The increases in current lag those in the wind by an interval apprently dependent upon wind duration; the longer this duration, the shorter is the time necessary to produce maximum possible current.

3) Rule-of-thumb relationships between wind and bottom-current speeds can apparently be formulated at least for Stations 5 and 13. For strong and sustained winds (> about 50 km/h) the bottom current at Station 5 will attain an increase in speed of 1 cm/sec for every 2 km/h increase in wind speed. At Station 13, the corresponding effect will be about 0.5 cm/sec for every 2 km/h of wind speed.

Inertial Currents

It has been previously noted that the major storm occurring in August 1975 supplied considerable energy to the bottom currents. In particular, several cases of significant rotary motion were recorded. It is believed that such movement is essentially inertial in nature. It may occur when water in motion is deflected to the right by Coriolis force and sent into a closed circular path. (Closed motion will occur only if the horizontal extent of the circular path is not too great, i.e. does not involve much change in latitude.) The inward-directed Coriolis force acting on the water is balanced by the centrifugal force. A relatively sudden impulse imparted to a body of water, and the subsequent "coasting" of the water without further interference, can generate inertial motion. Such an impulse can be supplied in nature by such phenomena as short-lived but intense storms. The period of the motion - the time for the current to travel a full circle - is dependent upon the latitude involved. In the area of interest (about 70-71°N) it is about 12.7 hours. This value falls among the semi-diurnal tidal periods (see Section 4.3); therefore, such motions will tend to dominate the tidal contributions at these periods. During the storm of early August 1975, the residual current became very nearly circular, at about

5.5 cm /sec, at Station 5 on the edge of the shelf. The tendency toward this type of motion was also present in more inshore areas, but was lessened presumably because of increased friction in the shallower depths. Similar effects were observed during the major storm in late August.

Manifestations of inertial effects can also apparently occur during periods of considerable ice cover - but are much more minor than those present during ice-free periods. This fact also tends to confirm that the circular motion is wind-induced, and therefore inertial in nature.

Summary

In summary, the bottom-current régime features a prevalence of northeasterly net motion both along the most seaward and over the easterly portions of the Arctic continental shelf between about longitude 128^{o} and 138^{o}W - at least during May through August. This prevailing current is apparently quite sensitive to wind speed but not to wind direction; the current, while maintaining its northeasterly "set" throughout any direction of the overlying wind, varies in speed with the associated wind speed. A clear explanation for this current is not yet available.

4.2.2.3 Sub-surface Circulation over the Alaskan Shelf

The presence of an apparently regular and dominant mode of sub-surface circulation over the Alaskan portion of the Beaufort Sea continental shelf east of Point Barrow (longitude about 156^{o}W) has recently been inferred. This circulation, which is essentially easterly in direction, occurs at least during the summer season. Data are as yet insufficient to document its presence during winter, although it is believed to occur during this period also. This motion is noted here because of its possible relevance to movement at depth over the Canadian part of the shelf.

The movement is revealed by both hydrographic and direct current data. The sub-surface water associated with the motion is characterized by a temperature maximum with respect to waters above or below. Off Point Barrow, the temperature can be as much as 5°C greater than the generally below-zero values prevailing in the adjacent layers. The temperature difference decreases to

the east, presumably because of the effect of mixing. The relatively high temperatures indicate that this sub-surface layer is not local in origin. It appears that the only possible source is water that has moved from the Bering Sea through Bering Strait into the Arctic Ocean.

The current itself appears to behave independent of overlying motions with regard both to speed and direction. It therefore is not generated by local winds although these appear to have considerable effect upon fluctuations, primarily those in speed, within it. It is believed to originate from the appreciable initial momentum possessed by the Bering Sea water upon entrance into the Arctic Ocean.

It has been suggested that this Bering water enters the Beaufort Sea itself by moving northeast through the Barrow Canyon which is located just northwest of Point Barrow. Speeds in this area can be considerable; typical values of 25 cm/sec and extreme values of over 100 cm/sec have been recorded. After the water has moved through the Canyon and is no longer thus confined, The Coriolis force is believed to deflect it to the right, along the Alaska shelf. Speeds decrease to the east; however, values of about 20 cm/sec have been noted at about 75 m depth at 151^{o}W.

One reason for noting the sub-surface circulation on the Alaskan shelf involves the possibility that this motion may penetrate to the Canadian portion of the Beaufort Sea shelf. It has indeed been suggested that this water may, under the proper combination of conditions, move as far east as the vicinity north of the Mackenzie River Delta before finally turning northward and entering the Canadian Basin. The hydrographic stations occupied on the shelf during the Beaufort Sea Project do not appear to show a temperature maximum with depth. However, sporadic data, especially those on the offshore portion of the shelf, may be insufficient to reveal the presence of such a sub-surface flow, particularly if the flow is intermittent and/or if its core varies in position with time. Also the temperature maximum may have been erased by mixing. Mid-depth direct current data are almost completely lacking in the Canadian area, so quantitative assessment of such motions is impossible. However, the northeasterly current trend believed to exist just above the shelf, for example, at Station 5, at a depth of $\sim$ 100 m bears consideration in this context.

Nevertheless, the question regarding the presence of a sub-surface flow over the Canadian Beaufort shelf that has originated in the Bering Sea and travelled over the Alaska shelf is still open at this writing.

4.3 Tides

4.3.1 Definitions

The tide, here, is considered to be the changes in water level generated solely by the effect upon the earth's oceans of astronomical forces such as the gravitational attraction of the moon and sun and the centrifugal force associated with the earth-moon system.

The tide has a continuous effect upon oceanic water levels and thus upon the corresponding degree of inundation of the neighbouring shore areas; it also can result in horizontal motion within the sea. It therefore has the potential of influencing the spread of waterborne pollutants both throughout the sea itself and over bordering land areas. Erosion and transportation of bottom sediments by tidal currents also must be considered.

These driving forces are periodic in nature. The totality of interactions between them can be extremely complex and the "theoretical" tide at any location can therefore best be described as the resultant of a generally large number of constituent periodic components. Such factors as friction, depth of water and the presence of land masses, can considerably modify the theoretical tide.

Other types of water-level fluctuations have their origin in meteorological, hydrological or seismological causes. The first of these can result in disturbances of sea level known as storm surges. Some features of such disturbances which have occurred in the Southern Beaufort Sea are noted in the next Section (4.4).

In general both vertical and horizontal motions involving changes in water level without, however, sea surface distortion or curvature that is apparent to the eye, are associated with the tides.

Tidal level (the height of the water surface at any time) is measured relative to "Chart Datum" which is, by international agreement, the plane below which the tide will seldom fall. In Canada, the plane of lowest normal tides has been adopted as the Datum.

The range of the tide is defined to be the difference in height between consecutive high and low water levels, relative to the Datum. Variations in tidal range are due primarily to the angular positions of the moon and sun with respect to the earth, and to a lesser degree, to the distance of these bodies from the earth. Maximum tidal ranges (spring tides) occur when the sun, moon and earth are in line, with respect to their centres. Minimum ranges (neap tides) occur when the moon-earth and the sun-earth line of centres are perpendicular to each other. Successive spring or neap tides occur at intervals of about 15 days.

The tides in the Beaufort Sea are essentially of the "mixed" type - a combination of semi-diurnal and diurnal components. The important components are: the so-called principal lunar semi-diurnal (M_2), having a period of 12.42 hours and, to a lesser degree, the principal lunar diurnal (O_1), with a period of 25.82 hours. Mixed tides have two high waters and two low waters every 24.84 hours, with a marked inequality in the heights of two succeeding highs or lows.

4.3.2 Tidal Ranges

Presently available information upon the tidally-induced variability in sea level in the Canadian Beaufort Sea has been obtained over the continental shelf, the area of most importance in the present context. Data were obtained primarily in April through May 1975, during the Beaufort Sea Project.

The tides, although mixed, are predominantly semi-diurnal with a large-tide range of 0.3 to 0.5 m. The tidal wave propagates eastward along the continental shelf. The range remains fairly constant at any distance parallel to the shore but is, however, generally smaller at the edge of the shelf than in the shallow waters and constricted bays at the coast. There is a noticeable slowing of the tidal progression (coupled with an increase in the magnitude of the diurnal component) as it approaches Baillie Islands at the eastern end of the shelf. As the tide propagates southeast into Mackenzie Bay, the range increased from 0.4 m at Herschel Island to 0.5 m at Shingle Point. Further south and in Shallow Bay, the tidal effects are overshadowed, during the ice-free season at least, by the effects of wind stress and outflow from the Mackenzie River. The normal tide range is about 30% of that at Herschel Island, but the mean-sea-level fluctuations, influenced by the two factors, are much larger than those at Herschel Island.

Across the northern end of Mackenzie Bay and seaward of Garry, Pelly, Hooper and Pullen Islands, corresponding stages of the tide are about 15 minutes later than at Herschel Island. In the shallow waters south of these islands, the range decreases to about 0.2 m but as is the case in Shallow Bay, the effect of the wind stress often completely dominates that of the tide.

The tide moves southward into Kugmallit Bay and also eastward, reaching Atkinson Point on the Tuktoyaktuk Peninsual about fifteen minutes later than it does Herschel Island. The tidal wave now turns and moves along the shelf perpendicular to the Tuktoyaktuk Peninsula, slowing appreciably as it reaches the western end. The magnitude of the diurnal K_1 component increases in the offshore direction by a factor of two or more, attaining values near that of the semi-diurnal (M_2) component; the tides can thus become quite diurnal at times.

North of Cape Dalhousie, the direction of propagation gradually changes from northeast to southeast. Inshore, the tidal wave proceeds into Liverpool Bay, increasing in amplitude, and reaches the entrance to Eskimo Lakes about five hours later than it does at Tuktoyaktuk. The tidal range at this point has increased to 1 m, a value greater than that encountered anywhere else in the Beaufort Sea. Offshore, the tide moves around Baillie Islands into Amundsen Gulf and south along the east side of Cape Bathurst into Franklin Bay.

It is to be noted that the maximum tidal heights and ranges encountered on the Beaufort Sea coast are very much less than those occurring on either the Atlantic or Pacific coasts of Canada; on both coasts, ranges of 5 m or more can occur and ranges of 3 m or more are fairly common.

As previously noted, tidal values in bays at the coast may differ considerably from values at offshore locations because of such factors as wind and funnelling effects within the bays. In addition, the presence of near shore areas of pack ice, which can occur during bad ice years, will alter water levels somewhat. Complete ice cover or shorefast ice will retard or negate the effects of the wind.

4.3.3 Tidal Currents (Tidal Streams)

Horizontal motions associated with the tide - tidal currents (streams) - have been monitored over the Canadian continental shelf of the Beaufort Sea for a considerable period. The complete results perhaps properly belong in a discussion of the circulation of the shelf, as has been given in Section 4.2; however, mention was made there only of the general magnitude of the streams encountered during the study. It is believed that, for completeness, the details of these motions should be noted here rather than in Section 4.2.

As remarked previously, the tidal streams observed just above the shelf appear generally to be no greater than about 1.2 cm/sec. (Surface currents due to tide can be expected to be of about the same magnitude.) Such small values might be

expected, since in this area the contributions of the amplitudes of the tidal constituents to the offshore water levels are small also. Consequently, for the most part, such movements will be masked by currents resulting from other effects. They too are semi-dirunal (except east of the Tuktoyaktuk Peninsula) in close agreement with the tides themselves which become very diurnal as they round Baillie Islands to enter Amundsen Gulf.

Over the shelf off the Tuktoyaktuk Peninsula the tidal streams, being mixed semi-diurnal, are dominated by the M_2 component. Both M_2 and K_1 components tend to increase toward the west; the greatest values recorded were 2.0 cm/sec for M_2 and 0.6 cm/sec for K_1. Both components tend to decrease off Mackenzie Bay to the west of the Peninsula. Off Liverpool Bay to the east, however, while the M_2 component was found to decrease sharply (from 1.2 to 0.7 cm/sec) the K_1 increased even more dramatically (from about 0.2 to about 1.1 cm/sec). It appears that, off Liverpool Bay at least, the O_1 constituent of the current can become larger than that due to K_1 (e.g. 0.4 vs 0.2 cm/sec at one station, and 1.4 vs 1.2 cm/sec at another).

The phase angles of the M_2 tidal-stream constituent are very different from the corresponding ones for the tidal-height component. The time of maximum flow advances from east to west take about nine hours to traverse the distance from Baillie Islands to Mackenzie Bay, whereas the corresponding time of high water takes about 2½ hours to cover the same distance but in the opposite direction.

In the case of the K_1 component, currents and tidal heights behave in essentially the same manner, both having cophase lines oriented roughly parallel to the coast. The phase of the tidal streams is about 90° different from that of the tide; thus slack water (minimum of zero value of speed) for this constituent occurs at the same time as do high or low water.

In summary, the tide propagates from west to east along the southern edge of the Beaufort Sea and the tide slows considerably as it rounds Baillie Islands to enter Amundsen Gulf. The tidal characteristics are basically mixed; they are semi-diurnal over most of the Mackenzie Basin shelf but become predominantly diurnal as the wave rounds Baillie Islands. The tidal streams associated with the tide are very weak, of the order of 2-3 cm/sec and are semi-diurnal. However, the time of maximum flow progresses from east to west across the shelf; the reason for this is not understood at the present time.

4.4 Storm Surges

4.41 Definitions

Storm surges are defined as changes in sea level, at a coastline, that result solely from meteorological causes such as strong winds and appreciable changes in atmospheric pressure occurring over the adjoining sea. Two types of storm surges are recognized: positive and negative. A positive surge (often called a storm tide) is associated with an increase in sea level at a coast. This increase is induced generally by a combination of onshore transport of water by winds and low barometric pressure. A negative surge is associated with a decrease in coastal water levels and results from wind-induced transport of water away from the coast.

Positive surges can result in significant flooding and erosion of the low-lying, unconsolidated land characteristic of much of the Arctic coast. Such effects can be accentuated in the presence of large astronomical tides or high waves accompanying the storm generating the surge. Flooding, especially if it involves oil-laden water, could damage or destroy all major wildfowl life inhabiting these low-lying areas, by contamination of nesting and staging areas as well as by its effect upon the birds themselves. Such ravaging of the bird population could entail an economic loss to the native population of the area as well as the aesthetic deterioration of the region. The deposition of oil or other pollutants on, or into, shallow lakes in low-lying areas such as the Mackenzie Delta could accompany such surges. The aftermath could be prolonged and destructive. The possible effect upon structures and operations associated with drilling for hydrocarbons also obviously bears examination at all times of the year. Wave action, especially that associated with the larger surges, could cause strong erosion; therefore, the retreat of the coastline, although presumably occurring continuously, undergoes its greatest rate discontinuously. Positive surges occurring in winter could conceivably move or damage any structures placed too near the water line. The stranding of driftwood 2 m or more above mean sea level along the entire coast from Herschel Island to Cape Bathurst indicates the degree to which positive surges can affect this area.

Negative surges, on the other hand, are not in general destructive to the coastline; however, they can be of importance to navigation in the case of shipping that must move in very shallow waters. For example, the approaches to Tuktoyaktuk (the only generally usable harbour in the southeastern Beaufort Sea) have a normal depth of only about 4 m; the utility of the harbour might be significantly lessened during the occurrence of major negative surges.

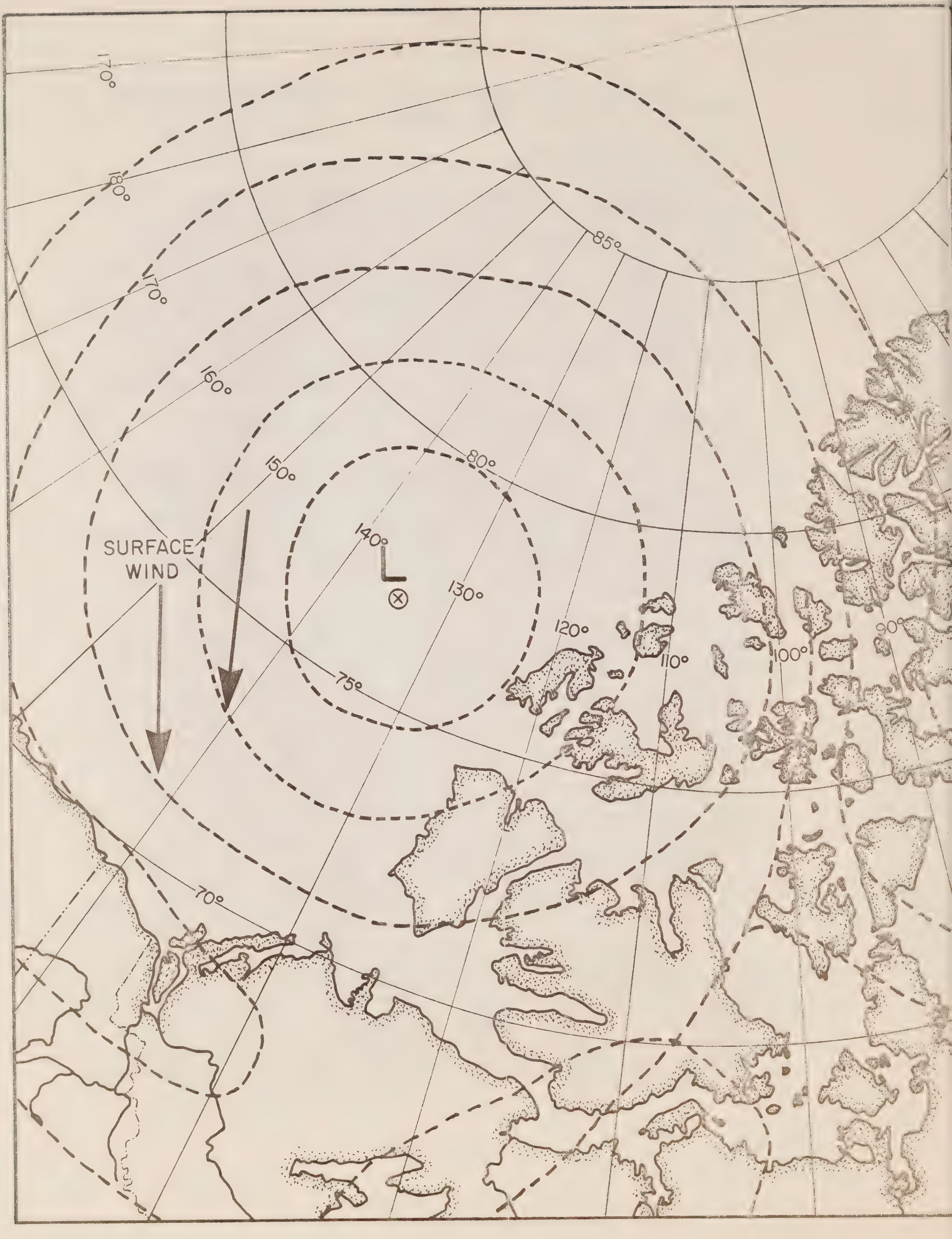
Information upon known surges is obtained primarily from water-level recorders (tide gauges).

4.4.2 Positive Surges

When the surface atmospheric pressure distribution dictates a strong wind blowing generally toward the coast (Figure 54), transfer of momentum from air to sea can lead to a shoreward-moving wave, and thus to onshore currents and transport of water. The resulting "pile-up" of water in the positive surge (Figure 55) is in general accompanied by a compensating reverse (seaward) flow at depth (Figure 56). However, in shallow water which extends for a considerable distance offshore (such as occurs on the continental shelf of the Beaufort Sea), this reverse flow can be strongly impeded or even overcome; the seaward escape of water can thus be lessened or negated, resulting in a higher water level than would be the case for deeper nearshore waters.

The wind-induced increases in sea level can be enhanced because of the attendant reduction in atmospheric pressure. During a positive surge, there will be, in general, a major increase in water level lasting for up to a day or more; however, under certain conditions of topography, storm track, etc., several further significant oscillations in level can follow the initial rise.

Along the coast, positive surges might be expected to be most marked in September and October - at which time northerly winds of appreciable intensity and duration, as well as a considerable expanse of open water adjacent to the coast, most generally occur. During the summers, the southern edge of the pack ice may retreat so far northward that, for purposes of the study of storm surges, the entire Beaufort Sea can be treated as clear of ice. The fetch - the distance over which momentum can be transferred directly from air to sea - is then limited only by the scale of the weather systems, and large surges can therefore arise if severe storms occur. A fetch of 50 km or more is believed essential for surge generation. In bad ice-years, on the other hand, the ice may remain within a few kilometres of the coast all summer, severely curtailing the fetch and therefore the surge activity. From this point of view of surge generation, relatively minor amounts of ice cover (2/10 to 3/10), together with a low probability of the accumulation of floes, may be effectively equivalent to open water. (Positive surging in winter would appear generally to be of much lesser effect because of the appreciable ice cover present throughout the Beaufort Sea.) However, little quantitative knowledge is at present available upon the modification of wind stress by the presence of partial or total ice cover.



170°
180°
170°
160°
150°
85°
80°
140°
130°
120°
110°
100°
90°
75°
70°
SURFACE
WIND

Figure 54

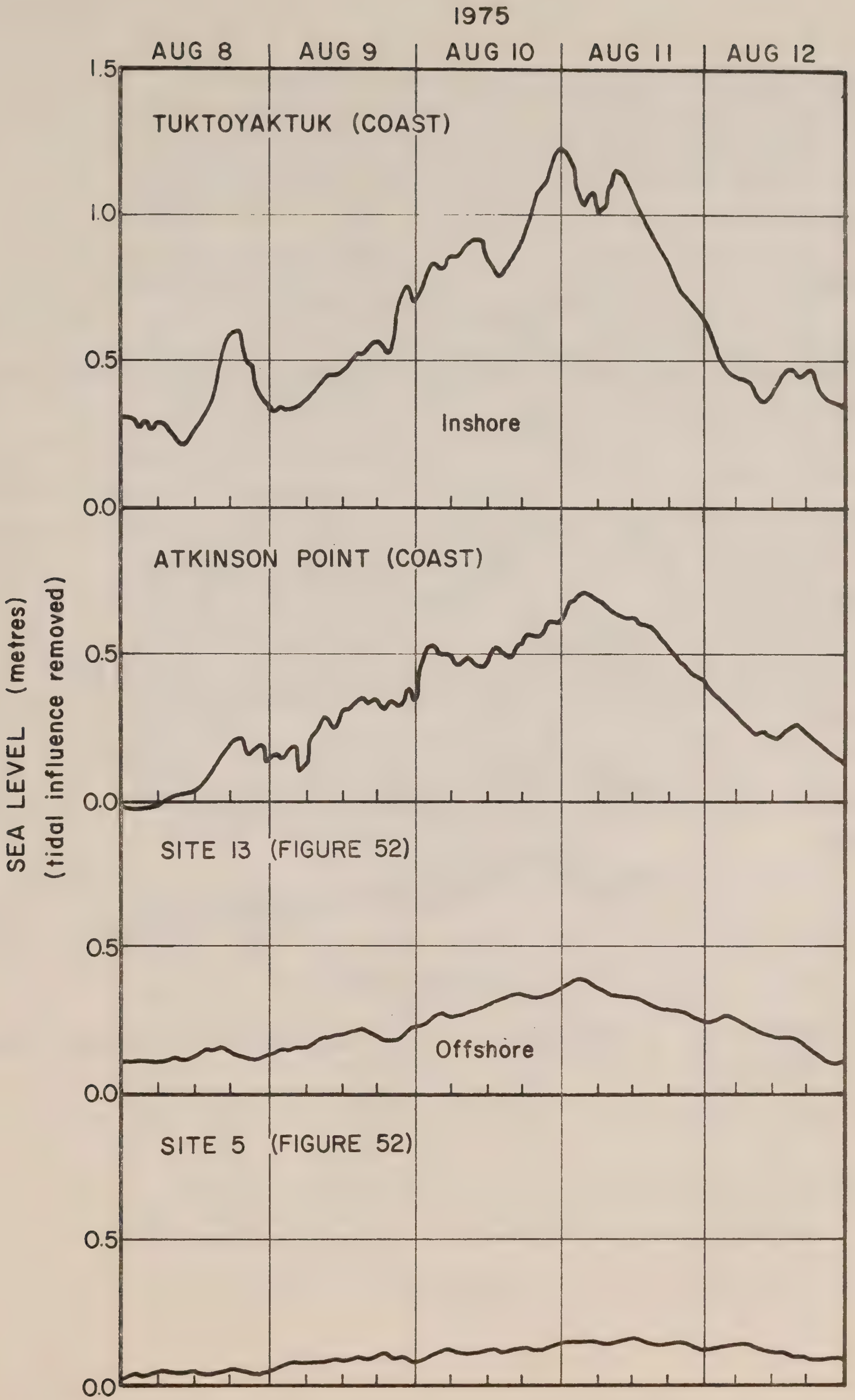

1975
AUG 8
AUG 9
AUG 10
AUG 11
AUG 12
1.5
1.0
0.5
0.0
TUKTOYAKTUK (COAST)
Inshore
ATKINSON POINT (COAST)
SITE 13 (FIGURE 52)
Offshore
SITE 5 (FIGURE 52)
SEA LEVEL (metres)
(tidal influence removed)

Figure 55

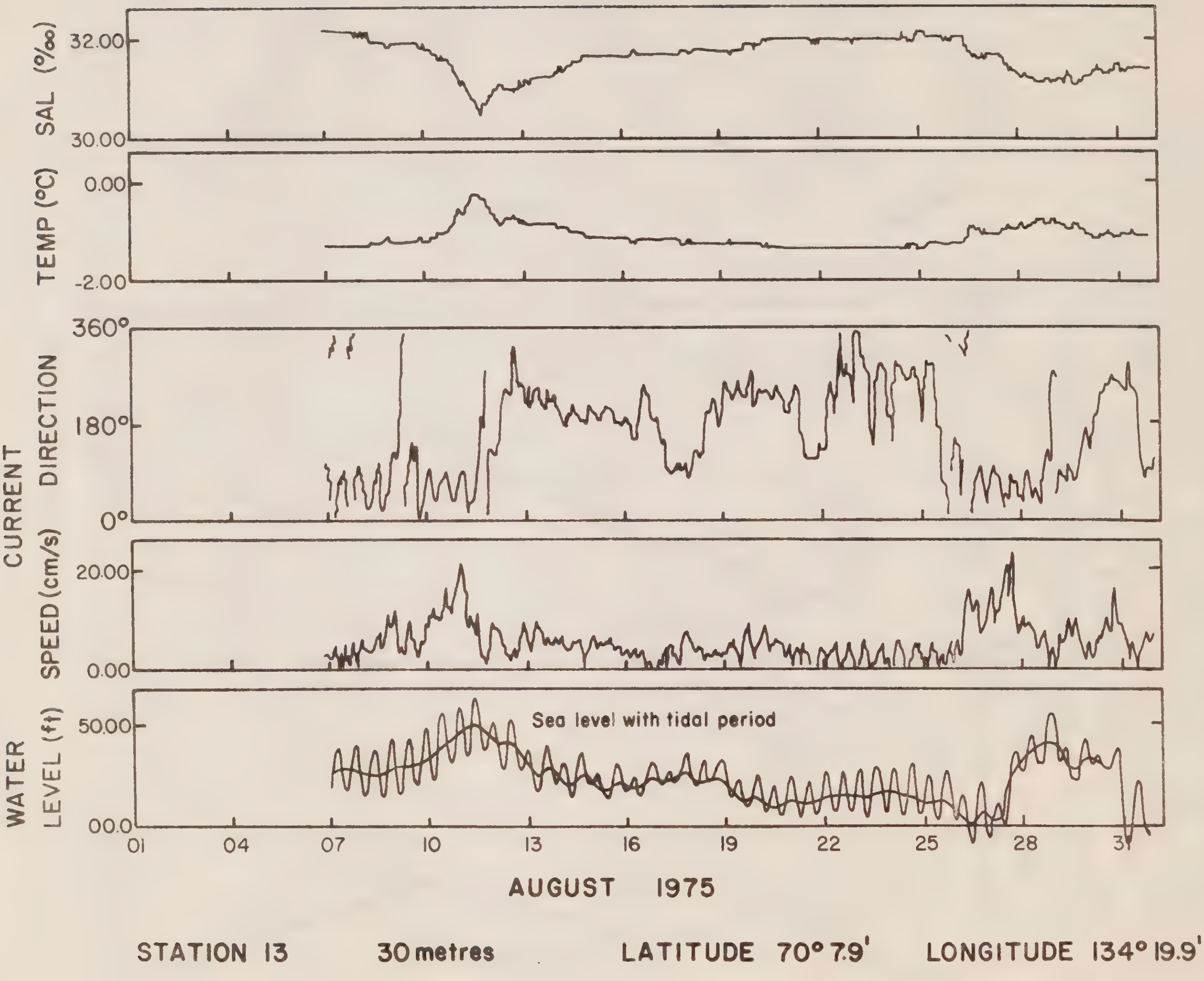

32.00
30.00
SAL (‰)
0.00
-2.00
TEMP (°C)
360°
180°
0°
CURRENT
DIRECTION
20.00
0.00
SPEED (cm/s)
50.00
00.0
WATER
LEVEL (ft)
Sea level with tidal period
01
04
07
10
13
16
19
22
25
28
31
AUGUST 1975
STATION 13
30 metres
LATITUDE 70° 7.9'
LONGITUDE 134° 19.9'

Figure 56

During summers marked by widespread ice cover, and in winter, positive surges should be rare or non existent. Especially in winter, such surges should result generally in water level increases appreciably less than those occurring in summer. It is to be expected that they nevertheless could cause unusual vertical displacements in the shorefast ice.

4.4.3 Negative Surges

The decreases associated with negative surges, in normal water level, are numerically smaller than are positive-surge values. Such decreases appear to occur most frequently in the September-November period, at which time southerly (offshore) winds can predominate; however, they can occur through the year, in contrast to positive surges, irrespective of the degree of ice cover.

4.4.4 Observations and comments

In 1962, a permanent tide gauge was established at Tuktoyaktuk. Numerous additional gauges (16 shore-based, 14 offshore) were in operation for various periods just prior to or during the Beaufort Sea Project. The data obtained (primarily from a few of these instruments) indicate that the above-noted expectations basically are correct. For example, between 1962 and late 1973, at least 23 positive surges were noted at Tuktoyaktuk, most of them occurring in "summer" (September or October). Ten occurred during 1963, a year featured by large areas of open water. Three of the surges exceeded 2 m above the normal tidal fluctuation of about 0.3 m. From 1962 to early 1974, apparently only two positive surges have taken place in winter; they were only about 1 m, appreciably less than those occurring in summer.

Mean sea level at Tuktoyaktuk has apparently remained essentially constant, on an annual basis, since gauging began in 1962.

Two large positive surges merit brief comment. One, in September 1972, was associated with an atmospheric low from the northwest. Winds of 125 km/h, gusting to over 150 km/h, were generated. At Tuktoyaktuk, the coastline was eroded by as much as 14 m, almost one-quarter of the total shoreline retreat recorded there between 1950 and 1972. The "return period" of this storm was indicated by extreme-value statistics (page 145) to be between 40 and 50 years.

An earlier (1944) surge was associated with winds of 130 km/h and with a mean-sea-level change of about 3 m. During the 1962-1973 period, only about five negative surges were recorded.

It should be noted that the inflow of fresh water can complicate the determination and study of storm surges, especially those of the negative type. If the polar pack reaches near the coast it can act as a dam, effectively confining the entrant fresh water to the narrow area between itself and the coast. As a result, water levels in the area can be raised appreciably and the study of surges confounded.

It has been stated previously that the shallow waters of the Beaufort Sea can be strongly stratified during the summer, especially near the coast. Such factors as large freshwater runoff can lead to abrupt and appreciable density changes and, therefore, layering within the near-surface waters. It is not believed at this time that such stratification significantly affects storm surges. Information is awaited upon the converse effect - that of a surge upon the degree and extent of stratification.

4.4.5 Forecasting of Storm Surges

The forecasting of water level changes induced by storm surges represents but one aspect of a capability for the prediction of weather and sea conditions - it is hoped up to 36 hours in advance - sought during and subsequent to the Beaufort Sea Project. The rationale is that such prediction of dangerous water levels, winds, wave conditions and ice movements will not only improve the safety of oil drilling operations, but will also reduce the risk of oil escape, since a full shutdown with all safety precautions applied can take up to several hours. It should also be emphasized that even a few unnecessary shutdowns could waste a substantial portion of the short summer drilling season, so that accuracy in prediction is highly desirable.

Other specific applications of water level forecasts should be to alert investigators of wildlife or of beach morphology to conditions of interest and, in the event of extremely adverse positive surge conditions, to permit the safe evacuation of personnel from low lying camps. Accurate prediction of significant reductions in water level in Tuktoyaktuk Harbour could be important to the activity of supply shipping.

An attempt to meet the need for predictive capability is being provided by the development of oceanographic and related meteorological models. In the storm surge aspect, a mathematical formulation (numerical model) of the oceanographic system in question is prepared. Changes in the system, over time and under specified conditions, are then calculated in a series of successive steps; a prediction is thus generated. The computations necessary to predict storm surges over a meaningful interval of real time can be extremely numerous, and the presence of a sufficient electronic computing facility is essential to the success of such a model.

Two such numerical oceanographic representations have been developed in the course of this study. One is a large-area model, which includes all areas of the southeastern Beaufort Sea known to have been ice-free on any occasion. Computation providing meaningful predictions applicable to the real-life conditions represented by this model is too involved or too costly for general use. The main functions of the model are to permit checks on the validity of conditions assumed for the small-area model (see below) and to allow detailed retrospective studies of particular storm-surge episodes.

A second, small-area model has been designed to meet the need of an operational forecasting system for storm-surge predictions; it is characterized by far more modest requirements than is the large one. Such restrictions as limiting the area modelled to the shallow Mackenzie-Bathurst portion of the continental shelf and its immediate environs have been employed.

A forecast of the surface wind regime in the area involved is indispensable to the success of these models. Simple methods to obtain this information have been employed elsewhere, but for a variety of reasons, these cannot at present be applied to the Beaufort Sea area. To remedy this deficiency, several more sophisticated approaches to the problem of surface-wind predictions are in progress. Numerical models are being employed in this aspect also.

Preliminary results from these procedures have been encouraging; however, much remains to be done before the desired accuracy for prediction of storm-surge (as well as other oceanographic) activity is obtained.

4.5 Waves

4.5.1 Definitions

Ocean waves generally result in highly-noticeable distortions of the sea surface. In the Beaufort Sea such waves, if of sufficient size, contain enough energy to affect adversely various marine operations - in particular, drilling operations from anchored vessels and the seaborne movements of supplies; compound the problems associated with spilled oil, such as mixing the impinging oil into the unconsolidated sediments common to the shores of the Beaufort Sea; cause widespread damage to shoreline installations; and hinder or prevent the application of many oil-spill counter-measures, by emulsification of the oil. To aid in minimizing such adverse effects, adequate information on the wave climate, as well as the ability to forecast accurately the state of the sea, are considered indispensable.

Ocean waves (with the exception of those of the capillary variety) are considered to fall into one of two classes:

a) Sea - consists of waves which contribute to the confused state of the water's surface within an area being actively stirred up by the wind. These waves are directly generated by the wind. A wide range of heights, lengths, periods and speeds can be present; these characteristics depend upon a number of factors including the sustained mean-wind speed and its duration, and the fetch - which control the degree of transfer of momentum from air to sea, and thus the intensity of wave formation. Periods range generally from about 3 to 8 seconds. There will be a sorting of the waves because of differences in speed; the faster waves will move out of the area of generation more rapidly than will the slower. "Sea" is shorter in length, steeper, more rugged and more confused than is "swell."

b) Swell - consists of waves which have outrun their generating storm. These fast, well-sorted, uniform waves decay (decrease in height) because of both frictional effects and spreading; the decay, however, is generally very slow. Waves that constitute swell tend to have long crests and to repeat themselves in regular sequences called wave trains. Their heights are small compared to their lengths, and their periods are of the order of 10 to 30 seconds.

The above definitions apply to deep water (short) waves - whose lengths are small compared to the depths of the water through which they are travelling. Wave behaviour at the coast depends upon the bottom topography. If the water depth remains large, with respect to the wave length, right to the shoreline, the waves will be reflected generally with little loss of energy. If the water shallows towards the coast and the depth becomes comparable to, and then less than, the length of the waves, the waves gradually become shallow-water (long) waves. This shallow-water condition will be obtained when the depth has become about 1/20 of the wave length. Such waves will be slowed, their height will increase, and their wavelength will decrease; if they approach the shore at an angle, their crests will tend to align themselves parallel to the bottom contours by the process known as refraction. The advancing waves will increase in height until a critical value (crest-to-trough height about 1/7 of the wave length) is reached; at this time the waves will become unstable and break (breakers), converting much of their energy to turbulence and frothing. The roiled water between the shoreline and the seaward limit of the breakers is generally termed "surf." An example is shown in Figure 62, which shows wave action associated with a positive surge.

Ice cover plays a major role in wave generation in Arctic areas because of its ability to eliminate wind contact with the water surface and thus to limit the extent of the fetch. In the southeastern Beaufort Sea, appreciable expanses of completely

open water may occur during the brief Arctic summer. These conditions, together with the presence of northerly (primarily northwest) winds, are the most propitious for wave generation in the area in question. However, during bad ice years, continuous ice cover may reach to within a few kilometres of the shore, and thus markedly inhibit wave generation. The presence of scattered ice floes within otherwise open water can also affect wave characteristics. These floes limit the height of waves by reduction of the fetch and by removing some of their energy on contact. Because the concentrations of floes are in a continuing state of change, it would seem that their effect can at present only be noted, and not quantitatively described, in wave forecasts.

Field data on waves occurring over the continental shelf of the Beaufort Sea are not numerous. However, some indications of the wave characteristics occurring can be provided for information obtained in 1975 and, to a much lesser degree, in 1974.

For convenience, working definitions of several terms in common usage in such investigations of waves as the one treated here are provided below. They apply to essentially a continuous record of wave heights.

a) Frequency - the number of waves per unit time; generally the units are hertz (cycles/second^{-1}).

b) Spectral Density (or Variance Spectral Density) - Terms referring to the amount of energy associated with a wave of the frequency being considered. The distribution of the energy over a range, or band, of frequencies is considered to be a form of the power spectrum for that frequency band.

c) Peak Period - The inverse of the frequency, i.e. hertz^{-1} (seconds), at which the maximum wave energy (spectral density) occurs.

d) Significant (Characteristic) Wave Height - The average crest-to-trough height of the highest one-third of the waves present in a sea. It is widely used in ocean engineering as an index of wave height. It is also defined as four times the area under the energy (variance) spectrum of the frequency band of waves being considered.

e) Equivalent Wave Height - $2\sqrt{2}$ (i.e. 2.83) times the square root of the area under the variance (energy) spectrum of the frequency band of waves being considered.

f) Percentage Exceedance - The percentage of the recorded waves whose heights (significant, maximum, or other designated value) exceed a given value.

4.5.2 Observed Wave Characteristics in the Beaufort Sea

During the Beaufort Sea Project, by far the greatest amount of valid data on waves was obtained during the summer of 1975. It was collected at 69°53.8'N, 135°57.2'W - a point about 35 km northwest of Pelly Island, off the Mackenzie Delta. The mean depth of water there is about 18 m. The data were obtained by a Datawell Waverider accelerometer buoy which recorded waves having periods between about 2 and 20 secs; the sampling period extended from 8 August to 6 September (29 days).

The study attempted to obtain a 20-minute wave record every three hours; the significant wave height was computed for each of these records. If the interval between successive 20-minute records was the expected three hours, a linear interpolation was carried out between records to produce a continuous trace (Figure 57).

Gaps in the trace indicate records missing because of failure of the recording equipment or of inability of recorded data to meet necessary quality control standards. The data percentage noted represents the ratio of the number of good 20-minute records obtained to the number of three-hour intervals in the 32-day period involved. The percentage of valid data for the interval is apparently of the general level to be expected with the type of instrument used.

Further examples of the graphic summarization of the information obtained are given in Figures 58 and 59. Figure 59 indicates the graphs of spectral density (energy) vs frequency for several of the 20-minute records. The term SWH refers to significant wave height. The greatest such height observed was 2.4 m, with a corresponding peak period of 5.9 secs in the variance spectrum; this was recorded on 11 August. More than 80% of the SWHs recorded had a value of <1 m. About 80% of the peak periods were less than 5 secs; effectively all were less than 6 secs, and more than one third were between 2 and 3 secs (Figure 59a). Figure 59b indicates the percentage exceedance for both significant <u>and</u> maximum wave heights; few recorded waves were greater than 4 m in maximum height. Almost 50% of the significant heights exceeded about 0.6 m, and about 50% of the maximum heights were greater than about 1 m.

On 26 and 27 August, much larger northerly winds were recorded than previously in the study, but the waves observed were generally smaller and of shorter period than were those occurring before. This was believed to be due to the edge of the pack ice being nearer the shore than previously, thereby reducing the effective fetch. The largest waves occurred during the presence of southwest or northwest winds; however, northeast winds also produced waves of appreciable size.

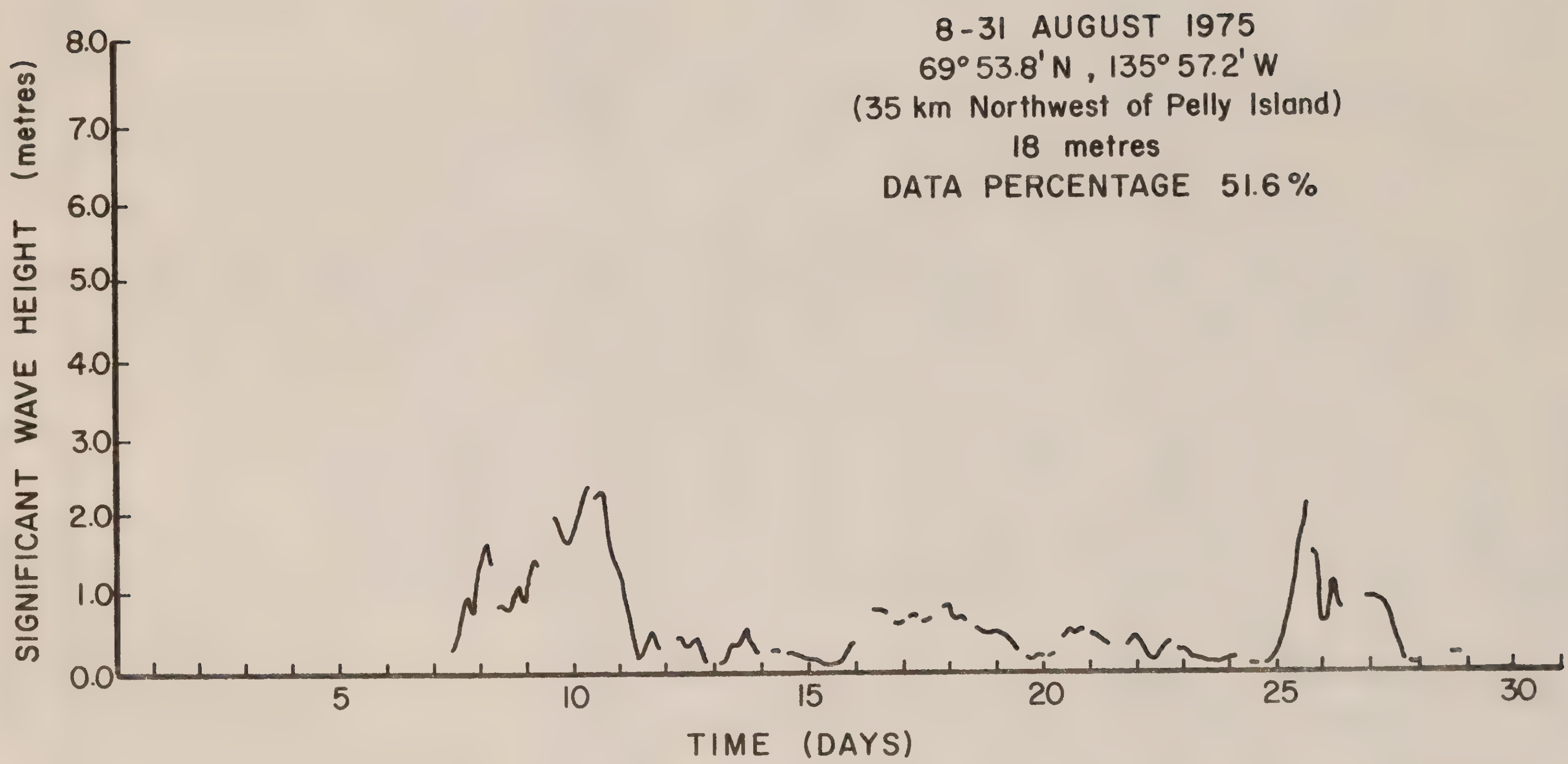

8-31 AUGUST 1975
69° 53.8' N , 135° 57.2' W
(35 km Northwest of Pelly Island)
18 metres
DATA PERCENTAGE 51.6 %
SIGNIFICANT WAVE HEIGHT (metres)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
5
10
15
20
25
30
TIME (DAYS)

Figure 57

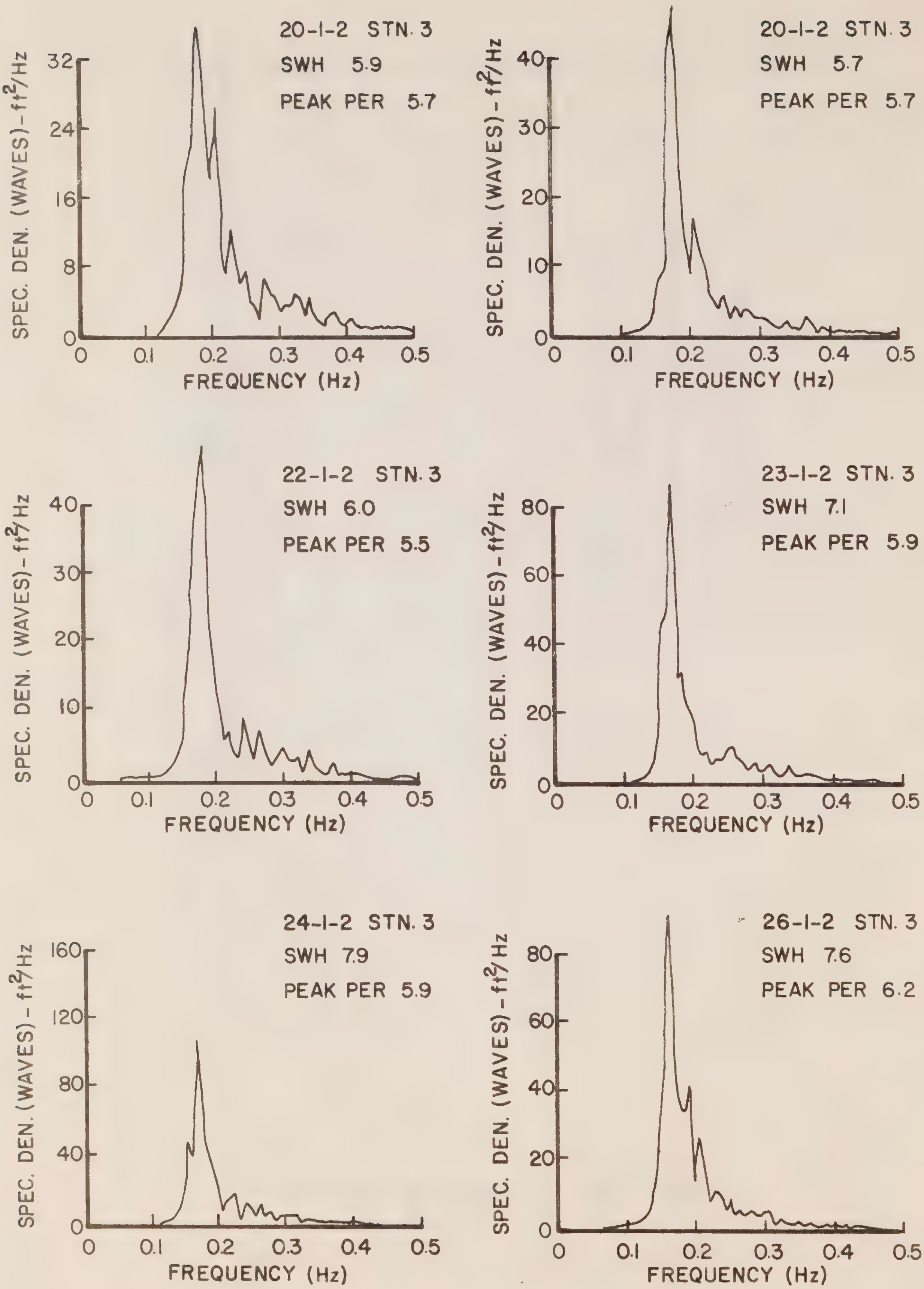

20-I-2 STN. 3
SWH 5.9
PEAK PER 5.7
SPEC. DEN. (WAVES) - ft²/Hz
FREQUENCY (Hz)
20-I-2 STN. 3
SWH 5.7
PEAK PER 5.7
SPEC. DEN. (WAVES) - ft²/Hz
FREQUENCY (Hz)
22-I-2 STN. 3
SWH 6.0
PEAK PER 5.5
SPEC. DEN. (WAVES) - ft²/Hz
FREQUENCY (Hz)
23-I-2 STN. 3
SWH 7.1
PEAK PER 5.9
SPEC. DEN. (WAVES) - ft²/Hz
FREQUENCY (Hz)
24-I-2 STN. 3
SWH 7.9
PEAK PER 5.9
SPEC. DEN. (WAVES) - ft²/Hz
FREQUENCY (Hz)
26-I-2 STN. 3
SWH 7.6
PEAK PER 6.2
SPEC. DEN. (WAVES) - ft²/Hz
FREQUENCY (Hz)

Figure 58

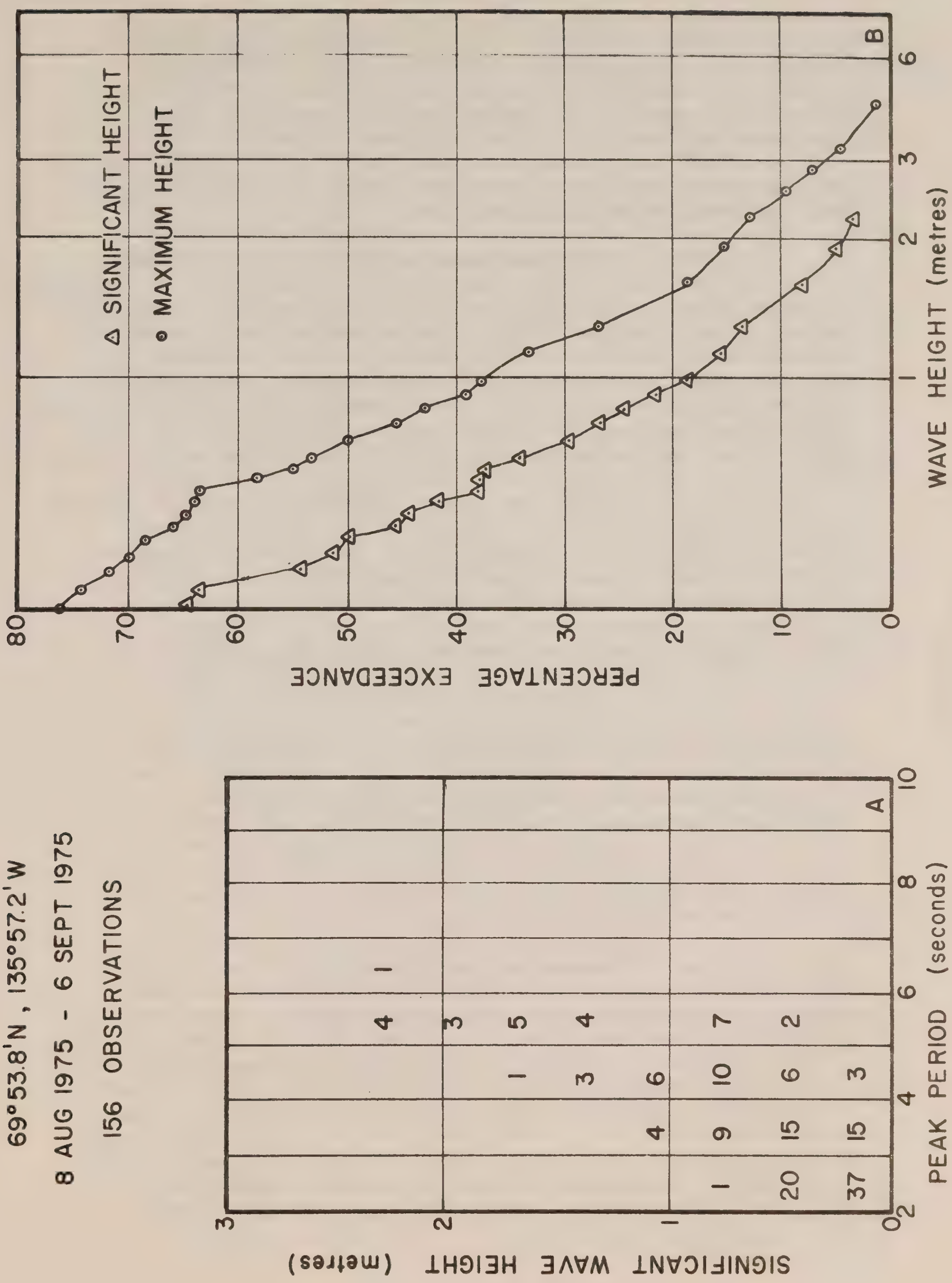

69°53.8'N, 135°57.2'W
8 AUG 1975 - 6 SEPT 1975
156 OBSERVATIONS
SIGNIFICANT WAVE HEIGHT (metres)
PEAK PERIOD (seconds)
A
Δ SIGNIFICANT HEIGHT
MAXIMUM HEIGHT
PERCENTAGE EXCEEDANCE
WAVE HEIGHT (metres)
B

Figure 59

An attempt had been made to obtain information on waves during the summer of 1974. The location chosen was $69^{\circ}46.6'N$, $133^{\circ}21.0'W$, at the entrance to Kugmallit Bay; the mean depth of water was about 10 m. As previously noted, 1974 was a markedly bad ice year. Drifting ice made it impossible to moor the wave measuring buoy until the latter part of August. When the buoy was finally in place, ice tended to greatly reduce the available fetch and to damp out waves of smaller period. Useful data were obtained for less than two days.

The greatest significant wave height recorded was about 0.63 m, with a corresponding peak period of 3.4 sec in the variance spectrum. The corresponding equivalent wave height for periods between 3 and 4 sec was 0.35 m. During the recording interval, the wind was greater than about 20km/h from the southeast for more than half a day. The wave heights recorded were generally smaller than those obtained in 1975; however, the very much shorter sampling period renders it injudicious to state that this fact was entirely due to the presence of such factors as lesser fetches.

For comparison with the results noted above, one can consider the following fact: with a fetch of 100 km, a wind of about 55 km/h blowing for more than about 8 h is required to generate a sea characterized by a significant wave height of about 2.5 m with periods of just over 6 seconds.

4.5.3 Prediction of Wave Characteristics in the Beaufort Sea

The data discussed above represent effectively the entire systematically collected numerical information on waves, in the Beaufort Sea, available to the time of this writing. Therefore, a corresponding lack of information exists upon such characteristics as the heights and periods generally, as well as upon the heights, periods, and frequency of occurrence of large waves. This represents a serious deficiency to various factors associated with oil seeking operations, such as the prediction of the feasibility of the sea borne movement of supplies and the integrity of shore or shelf based structures.

Wind data in the open southeastern Beaufort Sea are also few. However, they are much more numerous at several shore stations, records from five years to as great as 19 years being available for the area under discussion. The strong wind portions (storms) of this shore station information have been subjected to a combination of theoretical, empirical and statistical methods in an attempt to enlarge indirectly upon the knowledge of wave conditions in the area. Wind speed, direction and duration have been considered. For example, wind strengths of about 35 km/h occurring for periods of 12 hours or more are typical of the values that have been used. The over-land data of the

shore stations have been modified to the corresponding over-water values by considerations of such factors as that of difference in atmospheric stability in the two cases. To these meteorological values have been added oceanographic information dealing with such features as fetch and bathymetry. Maximum fetches in the area have been used, having been calculated from a study of the characteristics of pack-ice encroachment and of shoreline geography. Only open fetches have been considered; knowledge of the effect, upon the wind of a fetch, free of pack ice but containing isolated floes is weak at this time. Only simplified (linear) wave theory has been considered.

The following sequential series of results has been obtained primarily in the Mackenzie Bay and Franklin Bay areas.

a) Significant wave heights and periods for deepwater waves. The depth considered here is 75 m. Such wave characteristics could be assumed to occur in the open Beaufort Sea near the areas in question. The procedure used is known as "Wave hind-casting" and employs the so-called "Sverdrup-Munk-Bretschneider" (SMB) technique.

b) Corresponding wave characteristics after the waves have moved over the Beaufort Sea continental shelf and therefore become shallow-water waves. These values are obtained by recourse to the principle of wave refraction, which basically involves the change in direction of waves obliquely incident upon a shallowing area. The wave heights will in general also change.

c) The return period of waves having a given characteristic. For example, a wave of a certain height calculated to have a return period of 10 years (say) can be expected to occur about once every 10 years. The calculations invoke the extreme-value aspect of statistics.

Examples of deepwater wave characteristics (significant heights and periods) obtained by hind-casting - together with the primary meteorological and oceanographic factors involved - are given in Table VIII. The table deals with several storms that occurred during the period 1956 through 1959. (It may be noted that similar calculations have recently been carried out for the years 1960 through 1974.) Events during the four-month interval July through October have been considered, where possible; these months generally comprise the ice-free portion of the year in the southeastern Beaufort Sea.

The maximum shallow-water significant wave heights calculated for each month from July through October, for the 19-year interval 1956-1974 are listed in Tables IX (July and August) and X (September and October). The depths considered are: 50, 35,

TABLE VIII

DATE Yr/Mo/Dy/Hr	CLASS	STN	D (hrs)	U_L (km/hr)	T_A (°C)	T_W (°C)	$T_A - T_W$ (°C)	U_W (km/hr)	F (km)	F_e (km)	H_s (m)	T_s (sec)
56/7/05/15	2	SH	13	40	7.8	2.0	5.8	31.5	185	92	1.22	4.5
7/19/14	1	SH	15	40	-1.7	2.0	-3.7	36.9	296	129	1.68	5.0
8/09/11	1	SH	11	37	1.7	2.0	-0.3	34.3	139	74	1.22	4.5
8/21/17	3	SH	8	57	5.6	2.0	3.6	67.8	296	148	3.81	8.0
8/22/02	2	SH	5	59	-2.2	2.0	-4.2	69.4	111	92	3.05	7.0
9/20/00	3	SH	31	41	0.6	1.0	-0.4	49.1	694	351	3.50	7.5
9/22/22	2	SH	12	43	-1.7	1.0	-2.7	40.4	185	92	1.68	5.0
57/7/19/23	1	SH	11	39	0.6	2.0	-1.4	35.9	92	92	1.52	5.0
7/02/17	2	SH	6	35	4.4	2.0	2.4	32.2	37	46	1.07	4.0
8/07/17	1	SH	15	41	3.9	2.0	1.9	38.5	148	74	1.52	5.0
9/16/08	1	SH	21	41	-7.8	1.0	-8.8	47.5	111	92	2.13	5.5
58/7/06/09	2	SH	19	39	2.8	2.0	0.8	36.5	314	314	1.98	5.5
7/30/08	3	SH	27	38	11.1	2.0	9.1	45.4	555	277	2.89	7.0
8/07/03	2	SH	5	35	11.1	2.0	9.1	27.7	333	379	0.76	4.0
9/29/20	1	SH	17	34	-6.1	1.0	-7.1	39.8	518	370	2.29	6.0
10/17/03	3	SH	19	38	-5.5	0.0	-5.5	48.6	795	388	3.35	7.5
59/7/15/00	1	SH	13	39	1.7	20	-0.3	36.4	194	102	1.52	5.0
8/02/09	2	SH	8	40	3.3	2.0	1.3	38.2	152	74	1.52	5.0
8/20/33	3	SH	5	35	3.9	2.0	1.9	41.1	135	92	1.37	4.5
9/11/23	1	SH	10	39	-3.9	1.0	-4.9	45.1	240	83	1.98	5.5
9/07/05	2	SH	10	33	-2.2	1.0	-3/2	30.6	91	92	1.22	4.5
9/05/01	3	SH	34	41	3.9	1.0	2.9	48.6	407	203	2.89	6.5
9/30/09	3	SH	6	42	2.2	1.0	1.2	50.2	166	83	2.13	6.0
10/14/19	1	CP	4	59	-4.4	0.0	-4.4	69.4	46	46	2.74	6.5
10/04/14	1	SH	10	44	-8.9	0.0	-8.9	52.0	46	46	1.83	5.5
10/04/23	2	CP	6		-4.4	0.0	-4.4	73.1	54	37	2.59	6.5

....cont.

....Table VIII (continued)

STN = ONSHORE WEATHER STATION

SH = SACHS HARBOUR

CP = CAPE PARRY

D = Wind Duration

U_L = Wind speed over land

T_A = Air Temperature

T_W = Water Temperature

U_W = Wind speed over water

F* = Length of Central Radial

F_e = Effective Fetch Length

H_s = Significant Wave Height

T_s = Significant Wave Period

* A quantity related to the concept that fetch width regulates the effective length.

TABLE IX

Year	JULY Depth (m) 75	50	35	20	10	AUGUST Depth (m) 75	50	35	20	10
1956	1.7	1.7	1.7	1.5	1.2	3.8	3.7	2.8	2.7	2.9
1957	1.5	1.5	1.5	1.3	1.1	1.5	1.5	1.5	1.3	1.1
1958	2.9	2.8	2.0	1.9	1.8	0.8	0.8	0.8	0.7	0.7
1959	1.5	1.5	1.5	1.3	1.1	1.4	1.4	1.4	1.2	1.0
1960	2.7	2.7	2.7	1.2	1.0	2.9	2.8	2.4	2.1	1.7
1961	2.3	2.3	1.5	1.2	0.8	5.2	5.0	2.4	2.3	2.2
1962	1.7	1.7	1.7	1.3	1.1	4.1	4.0	2.0	1.8	1.7
1963	2.9	2.8	2.3	1.7	1.4	4.1	4.0	2.0	1.8	1.7
1964	2.4	2.4	2.4	2.3	2.1	2.0	2.0	2.0	1.0	0.8
1965	2.0	2.0	2.0	0.7	0.6	1.9	1.5	1.5	1.3	1.0
1966	1.4	1.4	1.4	1.2	0.9	2.4	1.9	1.9	1.6	1.2
1967	1.5	1.5	1.5	1.3	1.2	0.9	0.9	0.9	0.9	0.8
1968	2.3	2.3	2.3	1.0	0.9	3.0	3.0	2.0	1.9	1.8
1969	2.3	1.8	1.7	1.5	1.1	2.4	1.9	1.9	1.6	1.0
1970	2.9	2.8	1.4	1.3	1.2	3.0	3.0	1.7	1.6	1.3
1971	2.6	2.6	2.6	1.9	1.2	2.7	2.7	2.7	2.3	2.2
1972	2.4	2.4	2.4	1.3	1.2	3.8	3.7	1.8	1.7	1.6
1973	2.2	1.9	1.7	1.5	0.9	2.0	2.0	2.0	1.5	1.2
1974	1.5	1.5	1.5	1.1	0.9	2.4	2.4	2.4	2.3	2.2

TABLE X

	SEPTEMBER					OCTOBER				
	Depth (m)					Depth (m)				
	75	50	35	20	10	75	50	35	20	10
1956	3.5	3.4	1.6	1.6	1.5	-	-	-	-	-
1957	2.1	2.1	2.1	1.9	1.5	-	-	-	-	-
1958	2.3	2.3	2.3	2.0	1.6	3.4	3.3	1.6	1.5	1.4
1959	2.9	2.9	2.9	1.7	1.4	2.7	2.7	2.6	2.5	2.3
1960	4.3	4.1	2.0	1.9	1.8	4.3	4.1	3.3	2.2	2.3
1961	3.0	3.0	1.8	1.7	1.5	2.1	2.1	2.1	1.8	-
1962	3.3	3.2	3.1	3.0	3.0	4.6	4.5	2.7	2.0	1.9
1963	2.7	2.7	2.7	0.6	0.5	4.2	4.1	3.9	3.7	3.8
1964	2.4	2.4	2.4	2.1	1.7	1.4	1.4	1.4	1.3	1.2
1965	2.6	2.6	2.6	2.0	1.6	3.8	3.7	2.6	2.3	1.8
1966	2.7	2.7	2.0	1.7	1.4	2.3	2.3	2.3	0.5	0.4
1967	2.6	2.6	2.6	0.6	0.5	2.6	2.6	2.6	0.6	0.5
1968	3.4	3.3	2.0	1.7	1.4	2.3	2.8	2.0	1.8	1.5
1969	1.9	1.8	1.7	1.6	1.3	1.4	1.7	1.3	1.0	-
1970	3.4	3.3	3.3	3.1	3.2	1.2	1.2	1.1	0.8	-
1971	4.6	4.5	2.2	2.0	1.9	2.7	2.7	2.7	2.6	2.4
1972	3.0	3.0	1.5	1.5	1.4	2.4	2.4	2.4	2.1	2.1
1973	2.4	2.4	2.4	1.2	0.9	3.0	3.0	2.2	2.1	1.7
1974	2.3	2.3	2.3	2.2	2.0	-	-	-	-	-

-: No waves (because of, e.g., ice cover)

20 and 10 m. The estimated corresponding deepwater (75 m) wave heights (as exemplified by those given in Table VIII), upon which the shallow-water values are based, are also shown.

Tables XI and XII provide estimates of extreme values of significant wave lengths for return periods of 2, 5, 10, 20 and 50 years, and for water depths of 75 (deepwater), 50, 35, 20 and 10 m. Two periods are defined in the context: an "annual" period (July through October), and a "seasonal" period (July through September). October has been included in this manner since its winds are generally much more severe than those of the preceding three (ice-free) months. Table XII deals with the annual interval, and Table XIII deals with the seasonal. Included for each interval are the upper and lower limits characterizing the "68.2% confidence" band enclosing about two-thirds of the values calculated for the interval.

It is to be noted that the annual interval is marked by calculated wave-height values generally greater than the corresponding ones of the seasonal interval. The impact due to October values is estimated to be generally of the order of +10%, varying slightly with depth and with return period.

As previously indicated, the reliability of the computed extreme values falls off markedly for return periods greater than about twice the length of the wind records employed. Therefore, for the 19-year span involved in the present case, return values associated with periods greater than about 40 years (e.g. the 50-year values noted in Tables XI and XII) are considered to be of much less use.

In conclusion, three points regarding wave characteristics in the Beaufort Sea must be stressed;

a) As elsewhere, the worth of the calculated values of the deep-water wave characteristics is strongly dependent upon the reliability of the wind data used to generate them. Thus the quality of such data must be high.

b) Even if such deepwater wave values, which are in turn used in the estimation of shallow-water wave characteristics, are based upon good wind data, a high degree of accuracy in the bathymetric mapping of the Beaufort Sea continental slope and shelf is mandatory if the shallow water characteristics are to be useful.

c) The estimations and projections whose results, based on 19 years' worth of data, summarized above are believed to provide some indication of the actual wave characteristics (especially height) likely to be encountered at least in the southeastern Beaufort Sea. However, only a thorough comparison of calculated values with corresponding

TABLE XI

(a)

Return Period (years)	Depth (m)				
	75	50	35	20	10
2	3.2	3.1	2.5	2.1	2.0
5	4.3	4.2	2.9	2.6	2.6
10	5.2	5.2	3.3	2.9	3.1
20	6.3	6.3	3.6	3.2	3.7
50	8.0	8.2	4.1	3.8	4.6

(b)

Return Period (years)	Depth (m)				
	75	50	35	20	10
2	3.4	3.3	2.6	2.3	2.1
5	4.8	4.8	3.1	2.7	2.9
10	6.0	6.1	3.5	3.2	3.6
20	7.6	7.7	4.0	3.6	4.4
50	10.1	10.6	4.7	4.3	5.8

(c)

Return Period (years)	Depth (m)				
	75	50	35	20	10
2	3.0	2.9	2.4	2.0	1.8
5	3.8	3.8	2.8	2.4	2.3
10	4.5	4.4	3.0	2.7	2.7
20	5.2	5.2	3.3	2.9	3.1
50	6.3	6.4	3.6	3.3	3.7

TABLE XII

(a)

Return Period (years)	Depth (m)				
	75	50	35	20	10
2	3.0	2.9	2.4	2.0	1.7
5	4.0	3.9	2.8	2.4	2.3
10	4.8	4.8	3.0	2.8	2.8
20	5.7	5.8	3.3	3.2	3.3
50	7.2	7.4	3.6	3.8	4.2

(b)

Return Period (years)	Depth (m)				
	75	50	35	20	10
2	3.2	3.1	2.5	2.0	1.8
5	4.5	4.4	2.9	2.6	2.6
10	5.5	5.6	3.2	3.1	3.2
20	6.8	7.0	3.5	3.6	4.0
50	9.0	9.4	4.0	4.5	5.3

(c)

Return Period (years)	Depth (m)				
	75	50	35	20	10
2	3.0	2.7	2.3	1.8	1.6
5	3.6	3.5	2.6	2.2	2.0
10	4.2	4.2	2.8	2.5	2.4
20	4.8	4.8	3.0	2.8	2.8
50	5.8	5.9	3.3	3.2	3.4

actual values will provide a true measure of the worth of the former. Unfortunately, to this writing only a relatively small amount of data exists for use in such a comparison. Thus every opportunity should be seized to augment the field data on waves in the Beaufort Sea. Especially needed are those associated with very strong winds, at various fetch sizes.

5. POLLUTANTS IN THE ARCTIC ENVIRONMENT

5.1 Introduction

The Arctic environment is the result of an especially complex series of interactions between marine, atmospheric and terrestrial factors. However, the ecology - the totality of relationships between this harsh environment and the organisms living within it - has achieved equilibrium, albeit a delicate one. Nature has been able to devise many adaptations for survival within the region, not only in the case of vegetation and wildlife, but also in that of man himself (primarily the resident native population). All forms of life have until now lived in a high degree of harmony with the often relentless surroundings.

However, recent plans for strongly increased human activity in the region have threatened to change, perhaps irretrievably, this delicate balance. One of the obvious factors in such degradation would be any pollution associated with operations involving drilling for, and retrieval, storage and transportation of, oil and natural gas. During the course of such operations, the pollutants involved would most likely be introduced into either the aquatic or atmospheric portions of the environment. A brief review of several of the most obvious sources of pollution, as well as some of the natural and man-made factors that could affect the substances in question after discharge to the environment, is provided in the remainder of this section.

5.2 Waterborne Pollution

With respect to the aquatic phase of the total environment, by far the most significant pollutant that could be inadvertently released during drilling for, or storage or transportation of, crude oil is obviously the oil itself. Other substances that could undergo accidental discharge, and possess a potential for deleterious effects upon the water environment are: oil products associated with the drilling or transportation equipment itself, such as fuel and lubricating oil or hydraulic fluids; the "muds" (e.g. barium sulphate ($BaSO_4$)), which are used as lubricants in drilling operations and which often contain compounds, such as pentachlorophenol, that are toxic to many forms of marine life even at low concentrations; materials that could be used in oil-spill clean-up operations to disperse or to sink oil, such as detergents or dense powdered materials.

The crude oil could be discharged in a variety of ways:

- from oil-well blowouts;
- from punctured, ruptured, or sunken marine carriers, such as tankers and barges;
- from punctured or ruptured pipelines (submarine or land-laid);
- from punctured or ruptured storage tanks.

Fuels, lubricating oils, and hydraulic fluids could be lost from or by:

- punctured, ruptured or sunken tankers or barges;
- accidental or deliberate flushing of vessel bilges;
- miscellaneous leakage from drilling equipment;
- accidental spills during transfer of substances between locations.

Any loss of drilling mud would occur, accidentally or otherwise, during the drilling operation itself.

The presence of detergents would result from their deliberate introduction into the water, to aid in the dispersal of oil by emulsification (page 187). Alternately, dense powdered material, such as natural chalk (calcium carbonate ($CaCO_3$)), could be introduced for the purpose of sinking the oil.

5.2.1 Some Brief Considerations Involving Conditions During and Subsequent to Pollutant Spills

In terms of quantity of pollutants released, an oil drilling blowout represents by far the most dangerous and pervasive threat to the aquatic environment. For example, one postulated blowout in the area in question is considered to involve an initial escape of about 2500 barrels (400 m^3)/day.* This rate of release is assumed to continue for perhaps a month, then decline to about 1500 barrels ($\sim$250m^3)/day as the local region of the reservoir is drained. Therefore, a brief description of the major features characterizing such a blowout is in order.

A blowout may occur during drilling operations when the drill bit suddenly strikes a pocket of oil/gas at over-pressure deep within the earth. In the case of submarine drilling, a mixture of oil and gas will usually emerge from the seabed through a hole about 15 cm in diameter, the probable size of the drill hole casing at the point. (If the oil rises through a geological fault, it would probably enter the sea over a much wider area and therefore at a much lesser speed.)

It has been noted that, for blowouts at a water depth of 120 m or more, "slug flow," the alternate emergence into the sea of sections of oil and gas will predominate. In waters of about 20 m depth or less, "annular" flow is believed to occur, the oil surrounding a core of gas as it emerges into the sea. (The gas will expand as it moves upward from the sea bottom, due to a lessening of the surrounding pressure; a "bubbler" system

* 1 barrel - 35 Imperial (Canadian) gallons = 42 U.S. gallons = 0.159m^3

will be created.) The transition between the two types of flow is not clear in terms of flow rate and water depth, and there is a region of "froth flow" where the two fluids mix intimately. Experiments carried out by injecting oil-air mixtures into water under suitable pressures show that, for both slug and annular flow, the greater part of the oil rises to the surface in droplets of about 1-mm diameter; however, one to two percent of the oil is believed to divide into fine droplets of diameter around 50 μm i.e. $50(10^{-3})$mm. In contrast, oil injected into seawater in the absence of any air or gas floats upwards in droplets of diameter around 1 cm, there being a remarkably small range of droplet sizes. In annular flow, the oil emerges from the orifice as a coating on the air bubble, which then expands, shattering the oil into small fragments. The mechanisms of oil-drop formation in the cases of froth and slug flow are less dramatic but appear to produce the same result.

It appears that no matter what type of crude oil is involved in a blowout, it will, in open water, rise to the sea surface. After a somewhat complicated initial motion, which will tend essentially to confine the oil to a limited circular area, a continuous slick will be formed. Oil that has impinged upon an ice-water interface can undergo a complex series of events (which will not be further mentioned here). Because of horizontal transport by subsurface currents, the oil need not, however, reach the surface immediately above the point or area of release. The surface film of oil can be influenced by several factors. Effects due to wind, river runoff, tide and other factors will - singly or in combination - tend to propel the slick in the direction of the resulting motion.

The surface slick will remain continuous as long as a calm period persists. However, although such films of oil may tend to damp wave motion, presumably the wave-induced turbulence associated with strong winds will eventually break them up and perhaps even form stable or unstable emulsions (intimate mixtures of oil and water). Emulsions would be present to at least the depth of significant wave action. The density of the oil-water mixture is much nearer that of water than that of oil alone. If the emulsion is stable, therefore, it could be carried much greater distances by any currents at depth before rising to the water surface or to the ice-water interface. In the unstable case, emulsions will revert back to their original components as soon as the source of mixing energy is removed.

In the area dominated by outflow from a large river such as the Mackenzie - having a suspended minerogenic load which can be especially great during the freshet period - oil may become attached to suspended or sinking individual particles, or groups of particles. Such oil-silt aggregates may sink extremely slowly, and thus be significantly influenced by horizontal motions

at depth; if heavy enough, they sink directly to the bottom and therefore be influenced by any bottom currents of significant magnitude.

Untreated oil carried onto beaches composed of unconsolidated material would appear to be especially susceptible to wave action. It could be buried at depths as great as 30 cm or more, according to the nature of the beach material; subsequently it could be re-exposed and re-buried several times. Oil and material from a beach could also be aggregated, and either moved down the beach face, or be returned to the offshore water column at depth. Such actions are especially important on the mainland Arctic coast, where unconsolidated material such as silt and sand is the rule rather than the exception.

One effect of the general environment upon the released crude oil may be noted. Weathering, the loss of the lighter (more volatile) fractions of the oil, is a complex phenomenon, being dependent upon several factors: the temperature of the local environment and the presence or absence of wind, both of which can influence the rate of evaporation; waves; the nature of the oil in question, which can influence the solubility of these fractions in the receiving waters. In general, both the density and the viscosity of the oil will tend progressively to increase with time subsequent to the spill. Therefore, weathered oil is less likely to spread out on the water surface; in the limit, the original crude may be reduced to tarry lumps. Bacterial action and photo-oxidation may further affect the surface-lying oil; however, the effects of these agents may be suppressed in winter, in the Arctic, because of the cold and darkness.

Drilling mud, if released during an oil spill could aggregate with oil and remain for some time within the water column, temporarily at least; any toxic constituents would be released primarily at such depth. Otherwise, it will presumably sink directly to the bottom, with any toxic effects perhaps being at a maximum there.

5.3 Airborne Pollution

It has been emphasized previously that this report is concerned essentially with the aquatic aspects of oil-related pollution. However, we consider it relevant to comment briefly here upon a closely related aspect - the discharge during the drilling for or transportation of oil within Arctic regions, of substances having immediate or potential capability for environmental damage to the atmosphere.

The venting of such materials to the atmosphere could result accidentally as gas from a gas well blowout or as smoke from a burning gas well. It could also occur, because of deliberate action, as smoke resulting (ironically) from the burning of surface-lying oil (spilled

on land or on sea) during clean-up operations (Section 7). The degree of pollution will of course be governed not only by the amount of material discharged but also by the content of toxic, sub-lethal, or irritant constituents, such as sulfur or heavy metals, originally contained in the burning crude oil.

The primary danger associated with such discharges, should they involve such constituents, is the presence of atmospheric inversions. (An inversion involves an air temperature increase, and thus air density decrease, with height and therefore represents a stable situation.) In winter the average depth of the inversion layer is about 1,200 to 1,500 m. In winter, an inversion is usual and general, and results primarily from a negative radiation balance over the snow- and ice-covered surfaces common in the Arctic. In summer, it is present much less frequently; it can however occur when warm continental air moves over colder Beaufort Sea water. It can act as a barrier to the vertical dispersion of pollutants, thus trapping them at or relatively near the ground. The actual height to which such an effluent rises will, in general be dependent also upon the characteristics of the effluent itself - its temperature upon leaving the source and the height of the source itself; the latter consideration refers to such releases as those from stacks.

If no wind is present, the effluent may, because of an inversion, accumulate very near the source. Adverse consequences to visibility, as well as to health, may ensue. Alternately wind may drift the substances away horizontally from the source area. The concentration can thus be lessened near the source but increased to some, perhaps environmentally unacceptable degree, over considerable distances. However, the only means of quickly and effectively fumigating an area is through the action of brisk winds. It may be noted also that rain or snow (which of course are not generally associated with an inversion) will tend to wash out substances from the atmosphere and deposit them on land or sea.

The combination of atmospheric conditions that is most generally dangerous in terms of pollutant concentrations in the atmosphere - calm or light winds, and pronounced inversions - occurs far more frequently in the Arctic than in more southerly regions.

The percentage frequencies of surface based temperature inversions throughout the year at two locations bordering on, or near, the southeastern Beaufort Sea are given in Table XIII.

TABLE XIII

	Dec. - Feb. GMT		Mar. - May GMT		Jun. - Aug. GMT		Sept. - Nov. GMT	
	2300	1100	2300	1100	2300	1100	2300	1100
Sachs Harbour	75	77	32	67	16	44	38	47
Inuvik	58	67	3	60	0	61	25	46

The times 2300 and 1100 GMT (Greenwich Mean Time) are taken to be representative of late-afternoon and night-time conditions, respectively. Local time in the area is about seven to nine hours behind Greenwich Mean Time.

The tendency for inversions to occur during the polar-night (winter) period is evident. The inversions in winter are believed generally to persist throughout any daylight hours.

In summer (June - August), inversions are still frequent at night (44 - 61%), but are generally destroyed during the day (0 - 16%) because of diurnal heating.

The other important factors tending to create strong concentrations of airborne matter are the presence and duration of calms or of light winds. The percentage frequencies of calms for the year are given in Table XIV for Cape Parry, believed generally representative of conditions in the southeastern Beaufort Sea, and for Inuvik, near the coast.

TABLE XIV

	Cape Parry	Inuvik
December-February	11.0	29.0
March-May	7.5	11.0
June-August	3.1	6.0
September-November	5.3	17.0

This table indicates that the probability of calms, and thus of the associated adverse effects, is relatively great in the area during the autumn and winter periods shown (September-November, December-February), and least in summer (June-August).

The duration of calms or of light winds (2 to 20 km/h) at Cape Parry and at Inuvik can also be remarked upon. At the former location, the maximum duration of calms is greatest during the November-February period - 40 to 50 hours. The duration drops to 15 to 20 hours during the late spring and summer months. At Inuvik, the annual extremes are greater; as much as 60 to 90 hours in November-January, and as little as 10 hours in summer. The maximum duration of 2 to 20 km/h winds (10 to 20 hours) is common at both locations throughout much of the year - with the exception of December-January, during which time it can be as great as about 40 hours.

Thus, all features noted above indicate that - from the point of view of preventing possible atmospheric pollution - such operations as oil burnoff are best conducted during the Arctic summer rather than during the winter.

6. MOVEMENT OF OIL IN THE BEAUFORT SEA, AND RELATED FACTORS

6.1 General Background

This section attempts briefly to consider various environmental situations (scenarios) likely to be of major significance to the routes, travel times and geographical destinies of crude oil that has entered the waters of the Beaufort Sea. The oil is assumed primarily to have been discharged by a marine well blow-out on the Canadian Beaufort Shelf. However, it is hoped that the findings should also be of some aid in treating and ameliorating situations involving oil, or any other pollutants, discharged on the shelf or elsewhere in the Beaufort Sea by an inadvertent release - for example, the sinking or damaging of a laden oil tanker in transit.

Before elaborating upon the scenarios themselves, a few pertinent facts may be noted as background. In the area in question, offshore drilling from ships cannot usually commence before about the latter part of July, even in a good ice-year. Such drilling can in this case continue for no more than about three months - no later than the middle of October - because of the presence of pack or of shorefast ice. There is a possibility that ship-based drilling could be carried on within the transitional (shear) zone for a short interval during the freeze-up period - by use of ice-breaking vessels to protect the drill ship - although during this time the ice present within this zone is moving and actively shearing. However, in winter any ice in the zone is generally too thick to be handled by even the largest present day icebreakers, while at the same time it is in general too mobile to be used as a platform for the drilling of a relief well. In a bad ice-year, no drill-ship activity may be possible at all.

It is assumed that drilling to appreciable depths is necessary to penetrate to oil bearing strata; the chances of a major "new-hole" blowout would therefore appear to become more significant during the latter part of the drilling season (say, mid-September or later), if drilling were to commence as early in the season as possible. For example, during 1976, drilling was permitted only until about mid-September; it was assumed that the effect of any oil releasing mishap could possibly be nullified, or at least ameliorated, by allowing for an ice free month for the drilling of a relief well. However, on the basis of presently available technology and of knowledge of environmental conditions, it would appear unlikely that such a relief well could be made effective during the allotted period. In this event, the blowout in question would continue, unimpeded by human activity, for at least another ten months - until the commencement of the next (presumed) open-water period. Bad ice conditions during this season might, however, postpone effective relief measures for a further year. Under such circumstances, only the characteristics of the well itself, for example, the amount of oil available for release, or the possibility of the outflow being impeded or halted by sand or other geological debris entrained within the escaping oil or accompanying gas, would govern the outflow.

Four scenarios - each of which is considered generally characteristic of an appreciable portion of the year - are defined, utilizing as a criterion the general state of the sea-ice cover of the southeastern Beaufort Sea. The periods, and their scenarios, will be considered in the following order: summer (July through September) associated with open water over at least the continental shelf; freeze-up (September through November); winter, associated with maximum ice cover (November through April); and ice break-up (March through July). The overlaps indicated can be considered as implying the wide year-to-year variability possible for both the onset and the duration of any of these periods. Each scenario is, of course, hypothetical, but is believed to comprise of a mix of the relevant oceanographic and meteorological conditions which is realistic in the light of present knowledge. For the presumed occurrence of a well blowout (or other inadvertent release of waterborne pollutants) in summer, the scenarios taken in the above order should provide a realistic suggestion (but not necessarily a prediction) of the fate of any pollutants discharged during the summer and the succeeding periods of the year. Should at some future date an offshore well be drilled during other than the open-water season, examination of four successive scenarios - commencing with the one associated with the drilling period - should provide some useful description of the fate of oil inadvertently released during the drilling. Other accidents could, to the degree necessary, be examined in a similar manner.

6.2 Scenario I - The Summer Period (Approximately July through September)

6.21 General Oceanographic Conditions

1. The break-up of the landfast ice generally is complete along the Canadian Beaufort Sea coast by about early July. It may, however, be delayed until late in that month.

2. During the summer, the polar pack consists of multi-year floe ice, pressure ridges, rotted first-year ice, leads and polynas. Generally, the edges of the pack ice are distorted southward; protruding tongues and eddies of floe ice occur. Large floes break up into smaller ones.

3. The size of the open-water area between the coast and the edge of the polar pack is extremely variable on a year-to-year basis; it is dependent in great part upon the prevailing wind systems over the Beaufort Sea. If northerly (or westerly) winds prevail during the summer, a bad ice-year will occur. The pack may move as far south as 30 km from the shore. Southerly (or easterly) prevailing winds result in a good ice-year; the pack may move as much as 300 km or more offshore. Melting also tends generally to move the edge of the pack ice offshore.

4. According to the general nature of the year, floes of polar-pack or of rotting shorefast ice may drift to the coast and become grounded. Local winds and the outflow from the Mackenzie River may further modify the frequency of such occurrences; for example, offshore winds and strong river outflow will tend to lessen the number of such groundings, and onshore winds will tend to increase it.

5. Throughout this period, the outflow from the Mackenzie River is relatively large, although it will tend to decrease from about 25,000 m^3/sec in July to about 10,000 m^3/sec in late September. This fresh water is very turbid (containing much suspended minerogenic material), although to a somewhat lesser degree than during the freshet. It will move out over the saline waters of the Beaufort Sea as a plume.

6. The very stable surface layer associated with this plume will generally be about 5 m thick. If the area of open water is relatively small because of the shoreward encroachment of pack ice (a poor ice year), the layer can become appreciably thicker than usual because of the accumulation of fresh water between the shore and the dam formed by the ice. This fresh water can subsequently drain away from the enclosed area through any major leads established in the ice.

7. During calms, the plume will tend to consist of two more-or-less distinct flows, both being strongly influenced by the Coriolis force. One will move out of Mackenzie Bay and then eastward, past the northern end of Richards Island; the other, commencing in Kugmallit Bay, will move northeasterly along the Tuktoyaktuk Peninsula. Surface speeds will be of the order of 10-20 cm/sec (8-16 km/day). The marked salinity (density) difference along the perimeter of the plume (between the fresh water and the receiving sea water) provides a line (or zone) of convergence, especially near the mouths of the Mackenzie River. Horizontal mixing can occur between the two water masses because of the large tongues and eddies that often occur along the perimeter; this will tend to erase sharp differences in salinity or other properties. The eddies vary in size from 10 to 50 km; the most likely sources are instabilities along the perimeter between the Mackenzie River outflow and the receiving sea water, and interaction of the flow with topographic features. The associated motions tend to render details of the flow obscure and unpredictable. The problem is further compounded during very light, variable winds.

8. It appears that any relatively-common strong winds occurring near shore during the summer are either northwesterly ($\sim$35 km/h) or easterly ($\sim$25 km/h).

9. Northwesterly winds can result in southeasterly, onshore, surface transport of water at speeds of up to about 50 cm/sec

(approximately 40 km/day). A longshore current characterized by speeds of between about 25 and 75 cm/sec (20 and 60 km/day) is generated; the speed varies directly, but not apparently in a simple fashion, with the wind speeds. This current can extend as far east as the Cape Bathurst area. Its width can be as great as 50 km; however, the maximum along stream speeds are generally found about 10 km offshore. Under these circumstances, the Mackenzie River water will be confined to a narrow coastal band. A clockwise circulation probably exists in Liverpool Bay, and a counter-clockwise movement in Kumgallit Bay. The corresponding circulation in Mackenzie Bay has not as yet been well defined, although the presence of a northwesterly current, of speeds of up to 30 cm/sec (25 km/day) along the western shore of the Bay is indicated. In good ice-years, positive surges, and associated high waves, can be generated by such winds. These features can raise mean water levels by two or three m along the coast, flooding large stretches of the adjoining coastal lowlands and their thermokarst lakes, as well as causing considerable shoreline erosion. Several significant such surges can occur in the summer.

10. In a calm period immediately following a strong northwesterly wind, the longshore current will persist for at least two or three days before decaying. Water will flow northwest out of Kugmallit and Mackenzie Bays at speeds of about 20 and 40 cm/sec (about 16 and 30 km/day) respectively. A divergence is created in Mackenzie Bay, and a convergence forms north of Richards Island; some large eddies may be associated with the convergence.

11. Strong westerly winds generate effects similar to those for the case of a northwesterly wind. The easterly longshore current may be somewhat more accentuated by these winds than in the case of northwesterlies.

12. Strong easterly winds can lead to appreciable northwestward (offshore) movement of surface water (up to 75 cm/sec - 60 km/day - at least), and therefore a movement of the Mackenzie River plume to the north and/or to the west. Subsequently, a westward moving longshore surface current (of speed of about 35 cm/sec, or 30 km/day) will form. The seaward movement of surface water occurring in the presence of these winds can result in the upwelling of deeper water near the shore; negative surges, which are accompanied by depressions of 1 m or so in inshore mean-water levels, can also result. Similar effects can occur during offshore winds.

13. Bottom currents over the Canadian shelf area trend northeasterly at the outer and eastern portion; inshore they may be more southeasterly. They are variable but generally slow; net speeds are of the order of 10 cm/sec (8 km/day) or less.

Some sensitivity of these motions to surface-wind speed (but not direction) has been noted.

14 Current characteristics at intermediate depths are not well known; they need not necessarily be similar to those at or near the surface or the bottom. However, it may be noted that entrant freshwater entrains deeper water as it moves away from the river mouth; to replace any deep water thus moved seaward, a slow replacement shoreward flow must occur at some depth(s) below the surface layer. These opposing flows represent the basis of a positive estuarine régime.

15. Tidal currents are generally very small; their greatest effect apparently occurs in Kugmallit Bay.

16. The salinity (and the density) of the water in the surface layer is very much less than that at depth, e.g., 10°/oo or less vs about 32°/oo. The change in salinity with depth at the lower boundary of the surface layer is abrupt; the corresponding density distribution with depth is an extremely stable one.

17. Temperatures in the surface layer are much greater than those at depth, e.g., 4 to 8°C vs -1°C; the difference is due both to the originally warmer river water and to the subsequent retention, within the layer, of heat from the sun. Such temperature distributions will enhance the vertical stability of the surface layer.

6.2.2 Fate of Waterborne Oil During the Summer Period

1. In open water under (near) calm conditions, much of the oil issuing from a blowout will quickly attain the surface almost directly above the leak; dynamical interaction between the oil, the accompanying gas and the water will tend initially to confine the oil to a relatively small surface area. However, the oil will eventually move away from this area and form a slick. Both movement and formation will be accelerated by any surface-water currents driven, for example, by wind or by river outflow.

2. Should oil reach the surface over that part of the Canadian Beaufort Shelf north or east of the Mackenzie River Delta, it would tend to move slowly (5 to 10 km/day) in an easterly direction. Any oil droplets suspended within the surface layer should undergo basically the same motion, which is that of the Mackenzie River plume. Tidal contribution to the net motion is small. In the unlikely event of a prolonged period of calms or of light winds, the shoreline of the Delta and of the Tuktoyaktuk Peninsula could be contaminated by such oil within two to three weeks.

3. Weathering of oil under such conditions would be dominated by solar radiation.

4. At the offshore edge of the plume, there may be some horizontal mixing of the oil into the neighbouring waters as a result of large-scale eddy motion, particularly north of Richards Island and Atkinson Point; details of the motion would, however, be generally unpredictable. (Over the life of such eddies, oil could be concentrated within them as surface "clouds".) In open water, the oil so transferred would tend, in the case of calms, to move westward in the circulation of the southern part of the Beaufort Gyre, generally at about 2 to 4 km/day.

5. Oil moving at depths beneath the surface layer plume, e.g., the smaller particles that have been released after being propelled downward by the forces associated with escaping oil and gas, will tend to move slowly. Details of the motion at intermediate depths are not known at present. However, near-bottom net water movement will tend to carry oil shoreward over the inner portion of the shelf (that inshore of the 50 m bottom contour north of the Delta and the Peninsula) at a rate of about 2 km/day or less. At the seaward limit of the shelf in the same area, the motion will trend northeasterly at speeds two to four times as great. Such motions will also affect any oil-silt aggregates that have resulted from the interaction of oil droplets and suspended silt from the plume waters and are present beneath the surface layer.

6. In the presence of strong northwesterly winds, which are fairly common during summer, oil in the surface layer will be urged toward the coast at speeds of up to 40 km/day; the easterly movement induced by the Mackenzie River outflow will be strongly overshadowed. As the oil nears the shore it will move eastward, at even greater speeds, within a narrow band (no more than a few tens of km in width). If such winds were to continue for a few days, oil could be transported, for example, from the Delta area to the western end of Amundsen Gulf or to southeastern Banks Island (a distance of about 200 km) within a week or so. The oil would contaminate all shoreline features - spits, bars, barrier beaches, headlands, estuaries and lagoons. The oil would weather relatively rapidly during these winds, and at least would generally be more tarry in nature. Motion of the waters beneath the surface layer, and thus of any oil contained therein, will generally be much less affected, both in speed and in direction, by the wind.

7. Subsequent to strong northwesterly winds, the nearshore transport of surface-lying oil to the east by wind driven currents would cease after a few days; any easterly motion would then be due to Mackenzie River flow. Especially in the area north of the Delta, oil would tend to be carried to the northwest, toward the polar-pack ice. The movement might be modified, temporarily at least, by such actions as retention within the convergence north of Richards Island.

8. Strong westerly winds would have the same general effect upon surface oil movement as do northwesterly winds. However, the longshore speeds may be somewhat larger; therefore, the easterly transport of oil, and the extent of contamination, will be greater (after any appreciable period).

9. During a prolonged period of strong easterly winds, the surface-layer water and oil will be moved offshore, in a northwesterly direction, at speeds of up to 35 km/day; a longshore current of the order of 10-20 km/day can also result. Thus, freshly issuing oil from the Canadian shelf area can be transported offshore and to the west. It would, therefore, be moved into the pack-ice, onto the western shores of Kugmallit and Mackenzie Bays, or even onto the Alaskan portion of the continental shelf; the easterly tendency of the river flow would be masked in such conditions.

10. Strong southerly (offshore) winds would tend to move any surface oil toward, or into, the polar pack.

11. Oil entering leads in the pack-ice could be trapped within pressure ridges formed as the leads are destroyed. However (in contrast to the case in winter) this oil may be trapped only very temporarily. Oil pushed, or otherwise released, onto the surface of ice will be localized in pools of ice-melt water. This oil will thus be unable to participate in any movements within open water, but will be carried with the portion of the polar pack in question.

12. If the northerly extent of open water is great enough and northwesterly winds, or onshore winds generally, are of sufficient strength, positive storm surges can be generated. Such surges, especially the largest ones, are associated with a rise in mean water level of 3 m or more. They can bring about serious oil contamination at the borders of the southeastern Beaufort Sea. Beaches can be completely covered. Coastal bays and lagoons behind barrier islands - which would constitute natural traps for such floating oil - can be especially affected. Fairly frequent surges, together with the low rates of water exchange characteristic of the intervening periods, could severely burden such features with oil pollution.

13. In addition, surges and their associated wave activity can drive water and any contained oil a considerable distance inland over the generally flat coast. Thus, large areas of beach and tundra can become contaminated; oil can be trapped within thermokarst lakes, which are especially numerous on the Tuktoyaktuk Peninsula. (After the surge borne waters have receded, any possibility of oil removal from the lake by oceanic water movements will vanish.) However, a poor ice-year, with its relatively small amount of open water, will be featured by markedly reduced surge activity, both in strength and in numbers.

14. Oil can be incorporated into beach sediments, especially in the presence of strong wave action associated with major storms. This oil could eventually be re-introduced into the water column as the sediments undergo erosion. If it occurs as oil-sand aggregates, it may remain at neutral depths for a considerable period or move quickly to the bottom. Weathering of oil is reduced by incorporation into sediments.

15. Large amounts of surface-lying oil can accumulate by persistent ice damming during a poor ice-year. A major release of such oil through a large lead or leads can, for example, eventually concentrate oil on a fairly limited section of shore, with possible major ecological damage.

16. The previous remarks have dealt with oil directly attaining the surface or the water column. Should the summer in question occur approximately a year after a blowout, further oil will be present because of well leakage during the intervening year. Some of this additional oil will have been confined in the shorefast ice for a year, and subsequently released in late spring or early summer by upward migration through the ice and subsequent drainage into the water. Some will have surfaced by melting and/or breakup of the shorefast ice and of any snow cover on that ice. A certain amount will be present in leads, e.g. in those of the previous winter's transition zone. The oil will be in various stages of weathering, according to the time it has been on the surface.

17. Thus, in summer, it appears that after a relatively short period (a few weeks at most) newly issuing oil will have been widely distributed throughout the open-water area at least. Should the summer in question be that occurring approximately one year after a well blowout, oil released from decayed ice (primarily that of the shorefast variety) will also undergo such distribution. In addition, the

waterborne oil may have been spread onto the shores and to a considerable distance inland. It can also have been incorporated into beach sediments and into both the ice and the open-water areas associated with the polar pack.

6.2.3 Major Biological Consequences of Oil Pollution During the Summer Period

1. The bird population in the area at this time, while much reduced from the spring peak because of the early departures of non-nesting individuals, will nevertheless still be very large.

2. The barrier beaches and sandbars, especially those in the Mackenzie Delta-Tuktoyaktuk Peninsula area and along the Alaskan Arctic coast, will become important nesting grounds if they form islands inaccessible to terrestrial predators such as foxes. Several species, such as gulls, terns, ducks, and even shorebirds, utilize such areas.

3. In the early part of this period, nesting and the raising of young by seabirds can proceed in fresh water lakes. From mid-July through late-August these birds proceed to sheltered lagoons and bays behind beaches and sandbars; the features are utilized for rearing and for protection during the moult of flight feathers (at which latter time the birds cannot fly).

4. Estuarine areas associated with the Mackenzie and other rivers are utilized as major nesting grounds by geese, swans and ducks.

5. Crude oil can be spread into or onto the areas noted in (2), (3) and (4) by continuous water movements such as those due to prevailing surface currents or by isolated catastrophic effects such as positive storm surges or high river levels. Such contamination during the avian activities noted could decimate populations by such actions as smothering, poisoning, drowning, and exposure resulting from loss of plumage insulation.

6. Caribou and reindeer, seeking relief from summer insect infestations, often swim or wade in nearshore waters along the Beaufort Sea coast. How oil affects these animals in such circumstances is not yet known.

7. In July and early August, beluga whales, numbering in the thousands, seek to ensure calf survival by moving into the relatively-warm waters off the Mackenzie Delta, primarily those of Kugmallit and Mackenzie Bays. Prolonged onshore winds can tend to concentrate surface-borne oil within these

estuarial areas. This condition need not significantly affect the feeding by the whales, as they apparently do not feed in these locations; however, the oil may force them to move to less-benign calving grounds, resulting perhaps in both short and long-term adverse effects upon the population. Any displacement of the calving grounds of the beluga would entail some economic loss to the resident Eskimo population, which hunts these whales during their stay off the Mackenzie Delta. The whales depart westward along the Alaska coast before freeze-up.

8. Bowhead whales numbering a few thousand spend the summer in the eastern part of the southern Beaufort Sea, near Banks Island and Cape Parry. Any disturbance to them will depend upon the distance to which the oil moves eastward in significant amounts.

9. The effects of waterborne oil upon the phytoplankton and zooplankton are not yet clearly understood. The study of either direct or indirect effects may be confounded by changes resulting from other causes. However, the high turbidity associated with the Mackenzie River plume during large runoff could strongly reduce phytoplankton production within the plume. Oil remaining within the highly turbid area would have a correspondingly reduced effect upon total phytoplankton production over the shelf.

6.3 Scenario II - The Freeze-up Period (Approximately September through November

6.3.1 General Oceanographic Conditions

1. This period is marked by a decrease in the rate of outflow from the Mackenzie River. Throughout September and October the rate drops steadily, from about 15,000 m^3/sec to about 8,000 m^3/sec. During November, the reduction is the most rapid of the entire year; at the end of the month the rate of flow is about 3,500 m^3/sec, only about 15% of that at mid-summer.

2. In the Beaufort Sea, the easterly or northeasterly flow associated with the fresh water plume will be much weaker than in summer, and will therefore, in the absence of overlying ice, be more susceptible to the effect of wind.

3. Freezing generally commences in the northern part of the open water area, among the older floes along the outer fringes of the polar-pack ice, and spreads southward from there. The sheltering effect and other characteristics associated with these floes aids in promoting freezing. The commencement of freeze-up is dependent to a great extent upon the location of the edge of the pack; it will be earlier

for a case of strong shoreward encroachment of the pack during the summer.

4. The winter's shorefast ice will commence to form somewhat later than will ice at the edge of the pack. In periods of calm, it will form from new grey ice and from floe fragments. In November, it will grow in thickness and increase its area in a series of seaward steps, the degree depending partly upon the characteristics of onshore winds (see 6 below). All new ice, shorefast or not, will usually be less than about 1 m thick at the end of November.

5. The motion of any mobile nearshore ice (new or old) will tend to become westerly throughout the period, coincident with the decrease in strength of the easterly flow associated with the Mackenzie River fresh water. However, river water moving under completely formed shorefast ice will still tend, near the shore at least, to move eastward under the influence of the Coriolis force.

6. The autumn period is the stormiest of the year in the Beaufort Sea. In October, strong offshore winds can often occur, and newly forming ice can be driven away from shore and out to sea. These winds can be succeeded, in November, by northwest winds that can drive any free ice back to shore.

7. The time of complete freeze-up in the area occurs about the middle of October. However, there is great year-to-year variability; the time can vary from late September in a bad ice-year to well into November in a good ice-year.

8. Any strong onshore winds, primarily those earlier in the season, can generate modest storm surges (of height about 1 m or so); the surges and the accompanying waves, while generally not as large as those occurring in summer, can together still inundate flat coast to a considerable distance inshore.

9. During this period, several factors tend to reduce salinity and temperature (and density) differences between the surface layer and the underlying waters over the shelf. Convection induced by sea-ice formation and by wind induced mixing, for example, tends to erase the layer. However, especially under any completely formed shorefast ice, a thin (few m) slightly fresher and warmer than the water beneath may still occur.

6.3.2 Fate of Waterborne Oil During the Freeze-up Period

1. This is a transitional period between summer and winter conditions; as a result, oil released (or already present) at this time can undergo consequences associated with one or the other of these periods.

2. Oil from the blowout site rising to the surface in open-water areas will undergo appreciable horizontal movement, primarily as a result of storm induced surface circulation. A series of onshore and offshore wind régimes will tend to spread the oil in all directions, and perhaps provide a high degree of temporary emulsification.

3. The offshore winds in October will tend to move oil northward throughout the open water and even into the polar-pack ice. In the latter area it can undergo trapping in, and perhaps subsequent release from, leads; incorporation directly into the ice; or trapping, temporarily at least, beneath major floes. Such oil should tend to move slowly westward in the Beaufort Sea gyral circulation, and would generally not be available to contaminate the Canadian portion of the Beaufort Sea coast (see Scenario III).

4. Northerly winds will drive oil directly onto the shore and badly foul selected areas such as constricted bays, or lagoons behind barrier beaches. As already noted, such winds will additionally tend to establish alongshore currents of considerable speed and thus increase the length of shoreline contaminated (see Scenario I). Wave action can incorporate the oil into the beach sediments, in which it may remain for a considerable time; it can, however, also be reintroduced into the water column as oil-sand aggregates, or be moved along the bottom to greater depths.

5. The modest storm surges associated with onshore winds could be fairly frequent; coastal bays and lagoons could again be polluted, adding to any degradation contributed during the previous summer. The surge and the accompanying wave action could inundate flat shore-line areas to considerable distances inland; some interior lakes could thus be further contaminated.

6. Some of the oil will become incorporated into ice newly formed between storms. It may undergo release from this young ice if a subsequent storm tends to break it up. Some oil will presumably remain incorporated in the ice forming southward from the polar pack, while some will remain immovable within the shorefast ice when this has finally become continuous. The non-fast ice will tend to the west in the general Beaufort gyral circulation; any easterly

influence of the Mackenzie River outflow in the waters north of the shorefast ice will be small.

7. In open water, newly-leaked oil could undergo both weathering and emulsification by wind action. The emulsified oil can be present to greater depths than in summer, since vertical mixing will be enhanced by both convective and wind action, and by a lessened supply of fresh water. If this oil remains emulsified for some time, it will undergo the motions characteristic of the sub-surface waters. Such motions may or may not be similar to those at or near the surface.

8. Any older oil remaining from leakage during the previous summer will presumably have been strongly weathered by both wind and sun. This remnant will probably resist emulsification and thus tend to remain at the surface, perhaps as tarry lumps.

6.3.3. Major Biological Consequences of Oil Pollution During the Freeze-up Period

1. The major biological concerns during this period arise from the presence of appreciable numbers of marine and fresh water fishes which from October onward through the winter feed in, or migrate along, the shallow inshore waters near Richards Island and the Tuktoyaktuk Peninsula. For example, from October through December large numbers of whitefish move down the Mackenzie in a post-spawning migration, to end up in the deep low-salinity coastal bays and the lagoons. These protected waters also constitute rearing and nursing habitat for various species of fry that have been swept down the Mackenzie River soon after hatching. Large numbers of such fry are still inshore during autumn. The shallow inshore areas and the coastal bays and lagoons could be affected strongly by temporary or long-lived contamination by oil; heavy mortality could be caused to both immature and adult resident fish by suffocation or by poisoning.

2. In addition, fishes of value to a domestic or commercial fishery could be rendered unmarketable or aesthetically distressing, even though their contact with oil is non-lethal.

3. Heavy kills of both breeding and young components of arctic fresh-water or marine species may pose a long term problem. A prime reason may be the destruction, by oil incorporated into the sediments, of any bottom-dwelling organisms (benthic invertebrates) which act as food for such species. After a spill the recovery of the affected populations of organisms may be slow. As a result, the recovery of the fish population may also be delayed.

4. The impact of oil-polluted shoreline areas will be relatively low upon both birds and marine animals during September and October. Most seabirds, geese and shorebirds have migrated out of the Mackenzie Delta by late September and October. Ringed and bearded seals are present but not concentrated, and would probably avoid oil contaminated waters. It may be noted that healthy seals are apparently not permanently damaged by minor exposure to at least one type of crude oil occurring in the Beaufort Sea; stressed animals, however, can suffer heavy mortality after even short contact with this same type of oil. The Arctic fox is confined to the coastal tundra until the landfast ice has formed. During subsequent travel on this ice the foxes can avoid contact with oil. Some polar bears could be contaminated by oil especially in leads of shorefast ice; however, the direct effects upon these animals of such factors as oiling of fur and ingestion of oiled seal meat are as yet unknown.

5. Damage to invertebrate fauna in the intertidal zone would be small, since the zone is quite barren at this time.

6.4 Scenario III - The Winter Period (Approximately November through April)

6.4.1 General Oceanographic Conditions

1. During November and December, the shorefast ice will increase its area in a series of seaward steps which depend, partly at least, upon the strength of onshore winds present during the period. Such winds consolidate loose floes at the edge of the shorefast ice; these floes will then generally remain in place during any subsequent offshore drift. At maximum extent of this ice, the edge generally follows the 30-m bottom contour (approximately 50 to 75 km offshore), especially off the Tuktoyaktuk Peninsula. This first-year ice attains a thickness of about 2 m by April.

2. The pack ice is primarily multi-year in nature; however, some first-year ice is present, primarily having grown from open-water leads present during the previous summer. The pack ice encroaches southward to the 500-m bottom contour, which is located up to about 150 km offshore. The thickness of this ice is generally 2-3 m at its southern limit; ridges can attain heights of up to 12 m. This ice generally travels clockwise, southerly off Banks Island and westerly off the mainland, the motion being associated with the southern half of the Beaufort Sea Gyre. Speeds are slow but variable, being of the order of a few km/day; it appears that widespread networks of rectilinear leads can form at least in the southern stretches of the pack ice.

3. Between the landfast ice and the pack ice lies the transitional zone, which consists in great part of fragments of ice broken off from either side. The ice cover often in this zone is generally strongly-ridged and irregular in form. However, some open water can occur throughout the entire winter. (A boundary lead is present, throughout most of the winter, at the seaward edge of the shorefast ice.) Numerous "flaws" and "flaw leads" will occur in an unpredictable fashion, as the zone is one of very active shearing. By late winter, the lead pattern appears to alternate between a high density of short, coast-paralleling leads and a series of longer, wider leads perpendicular to the shore. The formation of ice in open-water areas, and its subsequent entrapment by their closure, can aid to some degree in the formation of pressure ridges. The frequency of occurrence of such ridges, as well as of first-year ice generally, increases as the landfast ice is neared. By about late January, the transition zone is generally in irregular motion to the west.

4. The Mackenzie River outflow is only about one-tenth of that occurring at the peak of the freshet; however, the flow is still of the order of 2500-3000 m^3/sec. Because of the nearly complete ice cover, the surface flow will be little affected by the wind. The entrant river water will therefore primarily move slowly in an easterly direction (to the right of the area of entry) under the influence of Coriolis force; this flow will occur generally beneath the shorefast ice.

5. The presence of the river water just beneath the ice cover can provide a thin (few-m) layer of water that is somewhat less saline than the deeper water (e.g., $28^{o}/oo$ vs $32^{o}/oo$). The water temperatures will be between -1 and -2^{o}C. The water at depth can be slightly warmer than that near the water/ice interface.

6. Positive storm surges involving relatively modest increases ($\sim$1 m) in inshore water levels can occur. These generally result from a certain sequence of winds: offshore motions which drive mobile ice seaward and therefore tend to provide some degree of open water (primarily in the transition zone), and then onshore winds which, in contact with such an area, can generate the surges. Because of the ice cover, any wave action generated in open-water areas will usually not be strong.

6.4.2. <u>Fate of Waterborne Oil During the Winter Period</u>

1. Above a blowout beneath either shorefast (or other stationary) ice, any gas accompanying the oil will fill all iregularities at the ice/water interface and form a relatively smooth surface. Oil will move easily outward under the gas at

least to the circular limit of influence previously noted (page 156).

2. If the amount of gas is small, or the gas is quickly lost to the atmosphere, the oil itself will then fill the irregularities at the under-surface of the ice.

3. In general, underlying gas will raise the ice sheet. Small-scale stress cracks can form in the ice. An ice sheet with uniform irregularities may undergo a major rupture; in this area, the succeeding replacement of gas and oil will pump oil through the cracks onto the ice and into any snow cover. If the snow cover is negligible, this oil can gather in any depressions, either natural or created by the weight of the oil itself.

4. Also, beneath shorefast ice, any warmer waters at depth can be raised to the surface by the bubbling action of the gas. The ice above the blowout can therefore be thinned by melting, making it more susceptible to escape of gas and oil. In the extreme case, this vertical circulation of warmer water could prevent freezing in the area and thus provide open water throughout the winter; oil could be confined to a certain degree in such an opening.

5. A slick or pocket of oil can be trapped at the underside of ice by pressure keels. (This can occur not only under shorefast, but also under moving, ice.) Oil which is stationary with respect to growing sea ice will eventually be incorporated into the ice during the winter. The oil will first penetrate a few centimetres into the ice; by late winter, growth at the bottom of the sheet will have ensheathed the oil. Oil thus fixed within shorefast ice will remain horizontally immobile until either it has attained the surface or the ice has broken up.

6. A blowout occurring in the transition zone will result in some oil directly reaching the surface in areas of open water. When calm weather occurs, this oil (emulsified or not) will freeze into any new ice as a surface layer; if the oil does not form an emulsion, it will freeze into the ice in its original form. Snow can be windblown into such leads and intimate snow-oil mixtures can result. The oil can remain at the surface if a lead persists - a noticeable example in the Beaufort Sea being the more-or-less permanent lead just to the north of the landfast ice. Any movement of contaminated ice or water will tend to be westerly, since the general nearshore circulation is no longer strongly affected by Mackenzie River outflow.

7. When an oil-containing lead is closed and a pressure ridge results from the "welding" together of ice blocks, much of the oil may be enclosed within the ridge. The presence of

oil can make such a ridge structurally weaker than if no oil were present.

8. Some of the oil rising under moving floes within the transition zone could accumulate in pockets formed by irregularities on the underside. This oil could move with the floe and eventually be encapsulated. If the floes move essentially westward - as is indicated - they could by the following summer period have transported oil several hundreds of kilometres away from the blowout, for example into the shoreline areas of Alaska; speeds would be of the order of 100 km/month. The oil could then be released during spring and summer by heating and by ice break-up. Some oil could accumulate on the surface (as pools or as snow-oil accumulations) by the rupturing or cracking of the floe by underlying gas.

9. Some oil originally reaching the surface in the transition zone could be transferred into the polar pack by movement of floes or by travel through a network of leads. It would then undergo the general westerly or southwesterly movement of the pack.

10. Any smaller oil particles formed soon after the issuance of oil from the well, may drift with the currents at depth for a considerable time before attaining either air/water or ice/water surfaces. While bottom currents on the shelf trend northeasterly, those at intermediate depths are not as yet well known; thus the areas where such droplets finally attain the surface could be quite widespread but are at present unpredictable.

11. Winter positive surges (and the associated rise of sea level, $\approx$ 1 m) could cause contamination of any ice free shoreline areas which the oil has reached. However, ice covered bays and lagoons should not be affected. A rim of oil could be produced along the edge of the landfast ice.

12. During periods of intense ridge formation occasioned by northerly winds, contaminated ice and water may be forced into the body of the landfast ice, and thus move considerably closer to the beach areas. This may pose added danger to these areas during the break-up in the following spring (see Scenario IV).

6.4.3 Major Biological Consequences of Oil Pollution During the Winter Period

1. Several thousand members of two seal species (ringed and bearded) are concentrated in transition-zone leads of the southeastern Beaufort Sea during November to April. They attempt to remain in ice-free leads to minimize the maintenance of breathing holes. Thus the probability of their

contact with oil is high, with the possibility of appreciable mortality if for any reason the animals are in a state of stress.

2. The food supply of bearded seals (large crustaceans, sea cucumbers, etc.,) will not in general be adversely affected by oiling of ice or water surfaces. The ringed seal, however, subsists on Arctic cod during the winter; extensive oil contamination of the leads will deplete the food of this fish and thus affect in turn this species of seal.

3. At present, the Arctic cod noted in (2) is the only fish to be adversely affected, actually or potentially, by seaborne crude oil.

4. Offshore leads are used by bearded seals for breeding as well as feeding. Thus, major oil pollution of these areas could heavily deplete young as well as older animals; recovery of the population in such cases could be slow and difficult. In contrast, the ringed seal's prime pupping habitat is the stable shorefast ice to the east of the Mackenzie Delta, an area that would be generally free from oil contamination in winter.

5. A depletion of seals indicates a lessened food supply for polar bears, as well as for scavenging Arctic oxes. If such a scarcity persists for several years, the distribution of both bear and fox could be markedly affected; even survival could be endangered. As previously noted, direct effects of oil upon polar bears are as yet unknown.

6. Bird life should not be significantly affected; major populations are not present in the area during this period.

7. In the short term at least, oil incorporated into the polar pack is removed as a threat to coastlines and to wildlife migration routes.

6.5 Scenario IV - The Breakup Period (Approximately March through July)

6.5.1 General Oceanographic Conditions

1. During May, the outflow from the Mackenzie River generally increases steadily from its winter minimum to its freshet peak (i.e. from a rate of 2500 m^3/sec to one of about 30,000 m^3/sec). It remains near this latter level throughout June and July. The amount of suspended minerogenic material within the river water (and thus the turbidity) also increases markedly and remains high. The outflow can generally be considered to be warm relative to the receiving marine waters. If it enters the sea under ice cover, it

will trend northeastward; after ice breakup its behaviour will tend to that characteristic of the open-water periods. It will re-establish a distinctive surface layer under the ice, as well as at the surface wherever ice has broken up and dispersed.

2. With the increase in the number of hours of daylight, an increasing amount of solar radiation becomes incident upon the ice. This radiation, after destroying any snow cover, will tend to promote upward internal melting of the ice (both polar-pack and shorefast). The degradation of the ice mass weakens it and, especially in the case of shorefast or other first-year ice, makes it extremely susceptible to break-up; first-year ice thus rotted has a "swiss cheese" appearance. The channels reaching the surface can drain any melt pools formed on the upper surface of the ice.

3. The breakup and/or the dispersal of shorefast ice will be expedited not only by solar radiation but also by the presence of the relatively warm Mackenzie River outflow. Coastal open water will generally first be present in Mackenzie Bay; it can occur as early as the latter part of May. Beaufort Sea coastal areas to the east will generally be clear about a month later. The northward drainage of fragments of the shorefast ice into open water to the north can be hampered by encroaching pack ice.

4. The first manifestations of the spring breakup of pack ice in the southern Beaufort Sea seem generally to occur off the Alaska coast in March. Prominent leads paralleling the coast apparently can in turn give rise to a family of long, very narrow north-south leads. Such networks then occur progressively to the east, the older more westerly groups successively tending to diminish or to disappear. The network forming near southwestern Banks Island can open rapidly and, after perhaps some refreezing and near closing, forms a large polynya abutting the shorefast ice in the area. This sequence is believed to result from the urging of easterly or southeasterly winds often prevalent at this time of year. During some years, because of a lack of such winds, a large open-water expanse will not form, and the area can remain heavily ice-bound throughout the spring and succeeding summer.

5. Along the Tuktoyaktuk Peninsula, the onset of the spring season usually corresponds to a progressive widening of the boundary lead, which can at this time extend from Amundsen Gulf to near Mackenzie Bay. The resulting open water can be considered as part of the large eastern polynya.

6. During the spring of some years, an extensive network of smaller leads can form in the Tuktoyaktuk area; they are

generally parallel to the shorefast boundary lead. This network can form natural pathways for spring wildlife migrations in the area. However, during other years, the network may be formed considerably to the south of the boundary lead, thus displacing the wildlife migrations.

7. Any given configuration of leads is transitory, especially in detail, generally persisting for a few days at most.

8. The ice in the transition zone becomes more finely divided than in winter, as a result of melting and breakup.

9. During this period, water movements in the transition zone (in the presence of shorefast ice) are generally westward but are extremely variable in speed (e.g. between 4 and 25 km/day), during March at least. The slower speeds will be characteristic of any cold period in which leads tend to refreeze.

10. The mean data of ice clearance along the Canadian Beaufort Sea coast occurs successively later to the east - a difference of about a month between clearance at Mackenzie Bay and that at the mouth of Amundsen Gulf (the end of June vs the end of July). However, the year-to-year variability is great. May can feature complete ice cover in the Beaufort Sea or show patches of open water in the eastern portion. In June, only Mackenzie Bay may be clear; in good years, the entire coast may be ice-free to 100 km or more offshore. In July, the Mackenzie Delta area and much of the coast adjoining the Tuktoyaktuk Peninsula are clear even during the worst of ice-years. In good years, open water can everywhere extend more than 300 km offshore in the Canadian area.

6.5.2 <u>The Fate of Waterborne Oil During the Breakup Period</u>

1. Of the oil escaping from the blowout, some will immediately attain the surface of open water (e.g., that of the shorefast boundary lead) and subsequently spread throughout it. If the shorefast ice is still continuous, at least some of any oil at the underside of the ice will be incorporated into the outflow of the Mackenzie River and move slowly northeastward.

2. As the main lead networks form within the pack ice, oil moving under, or encapsulated within, this ice may be released into the waters within the leads; as the networks decay, some of this oil may be re-incorporated into the ice.

3. By May, if the shorefast ice sheet still exists east of Cape Bathurst, oil escaping into the waters just under the ice or into nearby areas of the transition zone will be strongly urged to the northeast because of the greatly increased Mackenzie River flow. Such oil could enter at least the

western limits of the large polynya generally formed off southwestern Banks Island by May of most years.

4. By June, the steadily increasing solar radiation associated with the lengthening days of the Arctic spring will be rapidly rotting the shorefast ice by the enlargement of vertical brine drainage channels.

   If the breakup period in question is the first subsequent to a summer in which a blowout has occurred, the decay of this ice may provide oil additional to any that is still entering the environment by leakage from the blowout. The additional pollution will be due to oil that has been encapsulated into the ice during the previous winter. This oil can be released not only during any breakup and melting of the ice, but even while the ice is still in sheet form. Solar radiation will cause the imprisoned oil to migrate upward through the brine channel system to the upper surface of the ice; under such circumstances oil cannot remain stable in position within the ice itself. It can thus attain the surface even in the presence of some insulating snow cover, if the radiation is intense and prolonged enough. The oil may reach the surface as early as mid-May, but will do so more generally throughout June.

5. Each patch or aggregation of surface oil that has moved upward through the ice is initially unweathered. It will produce a melt pool; several of these pools may eventually join. The oil will remain in such large pools, strongly weathering because of the effect of solar radiation and/or of wind. The oil may be herded during winds and splashed into any remaining snow; further, it may undergo emulsification. Oil pools will drain into the surrounding ocean through any crack or lead that presents itself.

6. By July, warming by solar radiation (and by the Mackenzie River water in the relevant area) will generally have broken up the shorefast ice. Freshwater flow will tend to move fragments to the northeast while southeast winds, prevalent at this time during most years, will tend to move them northwest. The net effect will be to move such fragments, as well as transition zone ice, into the fringes of the polar pack over a considerable distance. Any encapsulated oil will, of course, undergo similar movement. This oil, as it is released by further decay of the ice (or by attaining the surface), could enter leads within the pack ice, and later possibly undergo incorporation into the pack by the closing of such leads.

7. The oil within the leads, as well as that still in ice fragments, could partake of the generally westerly motion associated with the Beaufort Sea Gyre. In the most extreme

case this oil, as well as any remaining in the melt pools and being refrozen in during the following winter, could move distances of the order of 1000 km by the following spring melting period. Thus, an oil pollution problem of some magnitude could present itself, at considerable distances westward of the blowout site, during the second or third spring or summer after encapsulation of oil within the ice.

6.5.3 Major Biological Consequences of Oil Pollution During the Breakup Period

1. May and June generally are characterized in the southeastern Beaufort Sea by the arrival of great numbers of migrant wildlife. These animals capitalize on the increased daily input of sunlight, the presence of relatively few predators, and the seasonal abundance of food - this last being based in great part upon the relatively high phytoplankton production occurring at this time. Any visible short- and long-term damage to each of these species will be a function of the vulnerability of the species itself to oil, as well as of the numbers of individuals involved.

2. Several million birds, mostly aquatic, converge in spring to nest in the Beaufort Sea area and the western Arctic generally. Seabirds, geese and shorebirds migrate eastward along the mainland coast during May and June. Spring lead networks as well as patches of open water and melt ponds, especially in or near the transition zone, are extremely important to the nesting and feeding activities of these migrants. The smooth water that would be generally characteristic of oil-contaminated leads is very attractive to diving birds, as are shallower leads in which bottom marine organisms would be sought for food. Sandbars and sheltered lagoons behind barrier beaches are important for nesting, raising and feeding; thus, oil either freshly escaped from a blowout or released from decayed ice could, if present in the localities just noted, play havoc with such bird life. Losses would be due primarily to exposure, but other factors such as poisoning might play a significant role. The possibility of long-term damage to the bird stocks can be great if the presence of oil is widespread along the coasts. The number of birds is at a maximum in June; thus new oil, and that released from ice, could have the greatest adverse effect at this time.

3. The first migrant arrivals in the area in spring are the beluga and bowhead whales. From late April till June, these species move eastward via leads and cracks in the transition zone, feeding on fish and other food. In particular, the beluga feed to sustain themselves during the summer calving period, at which time they eat little.

4. Both ringed and bearded seals breed from mid-March through mid-May, generally west of Banks Island and in Amundsen Gulf. They moult in the transition zone immediately before breakup, hauling out onto the ice. Both situations are, of course, stressful to the animals. Waterborne oil would foul appreciable numbers of seals; a large amount of oil, in conjunction with the weakening of the seals due to the stress, constitutes a potential for severe depletion of the stocks.

5. Adverse effect upon the numbers of seals would be translated into severe problems for the polar bear population, as it is strongly dependent upon seals for its food supply.

6. It appears unlikely that oil from a single blowout would threaten the long-term survival of the Beaufort Sea zoo- or phyto-plankton communities. However, local depletion of the important spring production and of the dependent invertebrates in the leads and ice of the transition zone could directly affect the food supply of whales and of seabirds migrating through the area.

7. REMARKS UPON THE UTILITY OF SOME OIL-SPILL COUNTERMEASURES PRESENTLY IN EXISTENCE

It is possible that natural factors, (water motion, wind, air and sea temperature), characteristic of the area in which spillage may occur, are incapable of destroying spilled oil or of reducing its concentration to innocuous levels; it may, therefore, be necessary to employ one or more techniques for its removal.

This section notes a few of the primary strengths and deficiencies of some of the simpler oil-spill countermeasures believed at present to be applicable, primarily during open water conditions. It does not deal with major engineering procedures that would affect the well itself - (such as the drilling of a relief well, or the containment of oil at the seabed by dome(s) anchored over the well site) - or schemes (such as trenching) for dealing with oil under the ice.

7.1 Burn-off

1. Burning is useful only against oil residing at the sea surface, at the surface of ice-melt pools, or in stationary (e.g. shorefast ice). In general it will be useless against stable emulsions (page 187), and of little value against crude that has been mixed with the unconsolidated material typically comprising the shoreline adjoining the Beaufort Sea. New crude oil will typically be readily burnable for a few days after it attains the water or upper-ice surface. Burning of oil would be accompanied by burning of the accompanying gas.

2. The older and more weathered the original crude becomes the less effective burning will be, due to a progressive loss by evaporation of the lighter, more flammable constituents with time. Up to several tens of percent of the original crude can volatilize within a few days. Strong solar radiation or high-speed winds will accelerate the process.

3. Oil that has been trapped within the ice throughout one or more winters should rise to the upper surface in spring, gathering in pools or patches of sufficient size to make burning practical. Early May, therefore, appears to be an optimum time to attempt burning-off. The use of aircraft (helicopters) is of great value in this instance, since the pools or patches may generally be scattered over a large area. However, the procedure can often be delayed long enough by poor flying weather that the oil will lose its more volatile compounds, and therefore become less amenable to burning. As the oil comes to the surface in individual bubbles, a single burnoff does not mean that the oil has been completely eliminated from the surface. More oil may surface, necessitating further firing. Several burn-offs may be necessary at progressively greater intervals should the supply of the oil steadily decrease.

4. Burning should also be extremely useful during calm periods within the open-water season. If surface currents are not strong, such conditions could favour the pooling of oil by the circulation associated with the gas induced bubbler system itself.

5. The presence of strong winds (> about 25 km/h) during summer could be deleterious in several ways: the oil would be maintained below its flash point temperature; weathering would be accelerated; the waves formed, if large enough, would tend to break up the slick into discontinuous patches or strips, or even form emulsions, thus hindering burning. Strong northwest winds could fairly quickly move the oil onto shore, thus rendering it less suitable for burning. Southerly or easterly winds acting on oil at or near the sites should generally initiate less of the adverse effects arising from either wave action or landward motion.

6. Spreading of the slick by horizontal currents of whatever origin will tend to lessen the tendency of the oil to burn.

7. One or more floes, of sufficient size, moving over a burn may extinguish it. Such an event is unlikely during the open-water season inshore; it is more probable in the vicinity of the polar pack.

8. Even in calm conditions, the burning of oil would create less persistent atmospheric pollution, per unit amount of oil burned, in summer than in winter; the difference would be due to the relative lack of low level inversions, and any attendant confinement of the exhaust, during the former period. The fact that significant burning of oil cannot at present be carried out in winter favours a clean atmosphere in the area.

9. In October and November, violent storms will tend to militate against successful burning; accelerated weathering, waves, and the wind itself acting on any burning in progress, will all be detrimental. The southerly (offshore) winds characteristic of October will tend to drive the oil into the encroaching pack ice. The northerly winds characterizing November can, in contrast, drive oil from the site relatively quickly into the adjoining shore. Both actions will effectively cause an apparently permanent loss of oil available to the burning process.

10. During any calm periods in October and November, some of the oil will be mixed in with the frazil stage of the newly-forming shorefast ice and will thus be less amenable to burning. Snow-oil mixtures can be created within leads, a further situation not conducive to effective burnoff. A number of large floes may provide a greater tendency to extinguish burns in progress.

11. During winter, any burning will be inhibited within open areas of the transition zone because of excursions of ice floes. The maintenance of open water by artificial means to increase the probability of successful burning, will probably be extremely difficult and costly. Oil-snow (poor-burning) mixtures will be common at this time.

12. As previously noted, any burning during calms in winter would tend to result in a maximum of local atmospheric pollution (soot) because of the increased likelihood of persistent low-level inversion. A tarry residue is another important by-product of the burning; it can amount to between 10 and 50 percent of the original volume of oil. Its disposal would present serious difficulties.

7.2 Mechanical Means, Such as the Use of Floating Equipment - Containment Booms, Skimmers (Oil-Water Separation Devices), and Floating Incinerators

1. Techniques employing such equipment are straightforward, but to this time little skill in their use has been accumulated, especially in the Arctic climate. A further disadvantage, associated to some degree with the previous one, is the relatively early stage of development of the

equipment itself.

2. It will be impossible to apply containment booms in the presence of pack ice, or even in open water containing numerous large individual floes. Thus, effective use would be confined generally to good ice-years.

3. However, even during good years, the booms (as well as skimmers used inside the containment area) could be successfully employed only during relatively calm conditions (wind speeds less than about 20 km/h, and wave heights less than about 50 cm). Oil riding the waves will escape over the top of a boom. Also, waves will break up an oil slick, thus reducing the efficiency of skimmers (even if they perform well mechanically). Periods of strong winds are quite frequent in the Beaufort Sea during the open-water season.

4. Horizontal water currents can also free oil from confinement by carrying it under the boom. The effect will increase with current strength.

5. The techniques would appear to be most effective in the clean-up of small, confined and relatively well sheltered bays. However, protection and/or clean-up along exposed coasts, even for very short stretches, could not in general be easily achieved by such techniques.

6. Separators and floating incinerators could be especially useful within inland bodies of water such as thermokarst lakes, which could occasionally become polluted because of catastrophic events, such as storm surges and very large tides and waves.

7. The final disposal of the collected oil, by such means as incineration or refining, could present a major logistical problem, because of such factors as equipment capability and transportability, and remoteness from major refining centres.

8. It appears that, even under ideal operating conditions, the conventional techniques and equipment such as those noted above could not at present be expected to provide a clean-up efficiency of greater than about 50 percent.

7.3 Sorbents, Chemical Dispersants and Bacteria

Oil will not, in general, form a stable water-in-oil emulsion during its passage from the blowout location to the water surface. The energy involved is apparently not suitably applied to the oil-water mixtures, since the oil droplets are too far apart to interact. Also, the oil may lack the surfactants necessary for emulsification. However, as previously noted, stable emulsions can be formed in a slick of suitable oil by

wave action; it can persist for a considerable time, and is generally quite viscous. Most emulsions of this type burn only with great difficulty, if at all. This drawback, as well as the general ineffectiveness of mechanical methods during a large portion of the open-water season, has led to a search for other possible means of countering oil spills. Those that have been applied elsewhere, or have been considered, are sorbents, chemical dispersants and bacteria.

Sorbents

Sorbents are materials which collect oil on their surface or sponge it up. They include substances such as straw, peat moss or plastic foams (e.g. polyurethane) which remain afloat after taking up the oil, and substances such as treated natural chalk ($CaCO_3$) which bind the oil into particles that sink after a relatively short time. (Calcium carbonate ($CaCO_3$) is two to three times denser than water.)

The advantage of the floating materials is one of cost, especially when compared to the present cost of chemical dispersants (see below). However, the logistical problems of handling the necessary amounts of even the most efficient of these materials at sea can be insurmountable, except in the case of small isolated patches.

(For example, it apparently requires about 20 tonnes of polyurethane foam to recover one day's release from a blowout discharging about 25,000 barrels per day. This amount of foam, density of approximately 0.03 gm/cm^3, would occupy a volume of about 600 m^3 (22,000 ft^3).)

Materials proposed to date for use in the sinking of oil are not overly expensive. The one most commonly considered has, up to now, been natural chalk. The logistics of the use of such substances is considerably easier than that for floating sorbents, since they are more readily handled, and the problem of their disposal will not generally occur. It may be noted that the efficiency of these substances should increase markedly with the age of the floating oil. (Oil becomes denser with time because of evaporation of the more volatile components. A far greater amount of sorbent would be needed when the oil is new and, therefore, lighter.) Important potential disadvantages are that the sunken oil may foul bottom-fishing and bottom-feeding sites, or may smother benthic communities - especially those in confined areas or bays. The latter drawback is, at present, probably of much greater significance in the Arctic because of the delicate ecological balance there.

Chemical Dispersants

The dispersants in question, if effective, will as the name suggests disperse oil in the sea; they do not, themselves, destroy the oil. They are detergents, but differ in several aspects from those of the household variety; they do not froth, and are much more stable since they must in general remain active for a relatively long time. If their use is successful, the small particles into which the oil is split will be so scattered that they will not re-aggregate, and will be (because of their small volume and large surface-to-volume ratio) in the best possible state for degradation by, for example, bacterial action or photo-oxidation.

The principle involved is the conversion of any viscous water-in-oil emulsion to a stable detergent oil emulsion which will then disperse. Two important components of the detergent are a surfactant, which is the primary oil emulsifier, and a solvent which enables the surfactant to mix with the oil and form the emulsion. The more volatile the solvent, the greater is its effectiveness, but also the greater is its toxicity. To be successful, dispersants must be very well mixed throughout the water. The energy for this could be expected to result primarily from wave motion; thus it would appear that, in the open sea, dispersants could be of maximum use during the periods when mechanical methods could not be applied. However, the energy need might often militate against their use in more sheltered locations (such as confined bays, or areas where the ice floe concentration is high).

There are at present several disadvantages to the use of dispersants also. While they have been tried with some success in temperate climates, it appears that available commercial types would be of only marginal value in cold waters. The toxicity of detergents is their major drawback, especially that associated with the volatile fractions of the solvents readily used. The surfactants are much less toxic than the solvents. However, they are not only denser than, and immiscible in, sea water but are also long-lived, not being readily degraded by microorganisms or volatilized; for example they may affect benthic communities by the creation of an anaerobic condition at the bottom. Even if other objections are met, however, the matter of cost and handling remains. If the amount of dispersant needed is of the same order as that of the oil to be treated, use in any situations except those involving short times and/or limited areas would become prohibitively expensive.

In summary, a careful and thorough consideration of any trade-offs involved would be necessary before a decision to use any of the non-mechanical countermeasures noted above

could be made. At present (1979) the use of dispersants in the Beaufort Sea is being discouraged as a matter of general policy. Any exceptions might be those circumstances where failure to use them could markedly compound the pollution problem, allowing disastrous contamination of important shorelines and/or wildlife. For those speedy decisions that would be necessary in many cases, a large background of readily-available information is indispensible.

Bacteria

Methods involving the controlled seeding of oil-attacking bacteria (augmenting those naturally occurring) to destroy spilled crude oil are still only in the consideration stage at the present time. Such bacteria break down oil into non-toxic components. The degradation might be efficient enough to be useful at the higher temperatures sometimes characteristic of melt pools on the ice or of brackish surface waters but impractical elsewhere in the Beaufort Sea much of the time.

8. SUMMARY AND REQUIREMENTS FOR FURTHER STUDIES

8.1 The Movement and Eventual Fate of Crude Oil (or Other Waterborne Pollutants) Released into the Southeastern Beaufort Sea: Summary of Conclusions

Several basic conclusions regarding the movement and destiny of crude oil or other waterborne pollutants introduced into the southeastern Beaufort Sea have been suggested; they can briefly be summarized as follows. (The lengths of all major seasons and periods noted are to be considered as approximate only.)

During the open-water summer season in the area (July through September), most of the oil newly released by a well blowout occurring on the shelf north or east of the Mackenzie Delta will, during calm weather, fairly quickly form a continuous surface slick. If the slick forms in the area influenced primarily by the Mackenzie River outflow, which is large at this time, it will tend to move slowly along the shore in a band (at speeds much less than 50 cm/sec) to the northeast or east. Even at this modest rate of progress, the oil could contaminate the entire shoreline of the Mackenzie Delta, and of the Tuktoyaktuk Peninsula within the space of a few weeks. Any oil present within the thin (<10 m-thick) brackish surface layer established by Mackenzie River water, e.g., in emulsified form, will undergo an essentially similar motion.

However, calms do not persist in summer; strong winds are frequent. The most significant of these are the northwesterlies, which tend to drive surface waters (and any oil contained therein)

shoreward at speeds of 50 cm/sec ($\sim$40 km/day) or more. Upon nearing the shore, the oil will be driven northeastward in a narrow (<50 km wide) current, at a rate of 40 km per day or more. The effect due to the wind will strongly augment that of the Mackenzie River outflow. If such winds persist, oil originally released near the Mackenzie Delta could be deposited along the coast between the Delta and Amundsen Gulf within a week or so. (Westerly winds will produce generally similar conditions, the easterly shore-hugging current may be somewhat more accentuated.) This motion may persist for up to a few days after such winds have subsided. If the north-south extent of open water adjoining the Beaufort Sea is large, strong northeasterly winds can generate appreciable positive storm surges. In this event, mean sea level at the coast may be raised by as much as 3 m. Areas bordering the shore, which generally are relatively flat and may contain numerous small lakes, could be inundated by a surge and its accompanying waves, and thus contaminated by oil. Wave action associated with such surges can mix oil with the unconsolidated minerogenic material which primarily comprises the beaches.

Strong easterly winds, which are less common in the open-water period than are northwesterlies, can drive surface lying oil westward and to seaward, especially in areas beyond the direct influence of the Mackenzie River. Oil leaking into such waters at this time will therefore be associated with a far smaller possibility of fouling the southeastern Beaufort Sea shoreline. Southerly winds also will move surface lying oil offshore.

If the expanse of open water is small because of marked pack ice encroachment, oil can accumulate within this expanse; the accumulation can subsequently be reduced by escape through ruptures and subsequently formed leads within the dam of confining ice. Local aggregations or depletions of oil may temporarily occur in open waters as a result of various factors, such as eddies formed along the perimeter of the brackish water, or convergences or divergences associated with the action of strong winds.

Oil entering the polar pack ice through a lead, or system of leads, can undergo several experiences, e.g. movement for a considerable distance into the ice during formation and destruction of successive networks or leads, or temporary incorporation into ice by any pressure ridging accompanying the destruction of a a lead. The general motion of such oil will be westward, with that of the pack; it will generally be lost to the southeastern Beaufort Sea area, but may subsequently be transported as far as the beaches of the northern coast of Alaska.

Floating oil will be strongly weathered during the open-water period by the combined effect of wind and solar radiation. Oil mixed into beach material will weather only slowly, until such time as it is released into the water column by wave action.

Therefore, at present it is believed that oil released by a blowout during the open-water period can be expected to be distributed relatively quickly throughout the entire expanse of open water and, as a direct result, incorporated to some degree within both beach sediments and at least the southern fringes of the polar pack ice. The details of the motions involved are not now readily predictable.

Oil leaking to the surface during the freeze-up period (October-November) will suffer marked weathering and emulsification during the strong winds often present at the time. Oil can be incorporated into newly forming ice as a surface layer. Oil that remains within completely formed shorefast ice will remain immobile until the breakup in the following spring. During the depth of winter (December through April) ice will cover effectively the entire Beaufort Sea with the exception of the transition zone, an area characterized both by numerous ephemeral leads and by a more-or-less permanent boundary lead at the seaward edge of the shorefast ice. Oil rising to the underside of ice can remain trapped and eventually become incorporated into the ice. Also, gas escaping with the oil can crack the ice; as a result, oil can be pushed out onto the upper surface of the ice and be mixed with any snow cover. Oil released originally into leads can be strongly bound into the ice during pressure-ridge formation. Oil entering into the much reduced Mackenzie River outflow, which will move under the shorefast ice, may still be transported, but very slowly, to the north or east. Wind will have little effect upon oil movement because of the sheltering effect of the prevailing ice cover. Oil entering the sea in winter will, in general, undergo little or no weathering during residence beneath the ice.

The breakup period extends from March through July. The earlier portion is marked by the formation of extensive systems of leads, primarily within the polar pack. Oil can be moved for considerable distances into the pack via these leads. By the end of July, the shorefast ice will have disintegrated, and the southern edge of the polar pack will have retreated northward to a greater or lesser degree. Newly released surface lying oil will, in general, encounter increasingly large areas of open water as the season progresses and, therefore, will be influenced more and more strongly by wind action. Also the Mackenzie River will be in freshet by May. Any oil entering th is Mackenzie River outflow will be borne strongly eastward (the effect being at an annual maximum during freshet). If the breakup period is the first subsequent to a summer blowout, the increasingly strong incident solar radiation will cause oil originally incorporated into the bottom of shorefast ice to migrate to the upper surface by the later stages of the period. It will weather at a rate according to its location: slowly in snow, rapidly in melt pools, eventually draining into the sea through cracks or leads.

Any oil that is encapsulated into ice more than one year old will not attain the upper surface of the ice until at least the second or third spring after incorporation. By the time of the earliest surfacing, such oil in polar pack ice may have moved many hundreds of kilometres westward. Thus, a mechanism exists for the deposition of relatively unweathered oil on the shoreline of a considerable portion of northern Alaska long after the original blowout could have dried up or been contained.

A lack of knowledge presently exists about the motion that would be undergone by oil at depths beneath the surface layer. It appears that in summer the net motion of emulsified oil near the bottom would be northeasterly at the edge of the shelf; over the inshore portions of the shelf the net motion at this time apparently tends to be shoreward but extremely slow. Motion at intermediate depths during any season is still poorly known at this writing. The effect of tide, especially upon the net motion of oil, appears generally to be insignificant except perhaps at a very few locations, such as Kugmallit Bay.

It may be noted that an oil well blowout in the southeastern Beaufort Sea could have severe effects upon the ecology of the area. Some wildlife populations, especially sea birds, could suffer heavily. However, complete recovery probably would occur, although slowly, provided that further blowouts or even an appreciable amount of delayed effects from the original blowout did not occur. There would be some summer deprivation by the resident native population because of the disruption inflicted upon the wildlife. Aesthetic losses both to native peoples and to those in many areas far removed from the Beaufort Sea could also be significant, although these would not be readily quantifiable.

8.2 Some General Recommendations for Further Studies

In the preceding chapter, numerous characteristics have been suggested for the pathways followed by, as well as for the eventual fate of, crude oil or other waterborne pollutants released over the continental shelf of the Beaufort Sea. This catalogue of possibilities implies that a considerable amount of basic knowledge has been gained upon the physical oceanographic, and closely related, aspects of the area in question. By far the greater part of the data involved has been obtained during the course of the Beaufort Sea Project, which was carried out during 1974 and 1975. However, detailed assessment of the information has indicated that several significant gaps in knowledge remain, in basis as well as in detail. As examples, data upon subsurface currents over the shelf, with the exception of movements near the bottom, are practically non-existent; additional information is vitally necessary for the development and/or refinement of predictive models proposed to deal with such features as storm surges, large-scale ice movement and wind-surface-current interrelationships.

Some specific areas of interest which demand considerable further investigation are noted briefly below:

1. Characteristics of the Surface Wind over the Beaufort Sea Area

   The characteristics of the wind (e.g, speed, direction, prevalence during various periods of the year, stress imparted to various types of surfaces such as ice or water) are of great importance to the prediction of the transport of pollutants. Mention is made of these factors in several instances throughout the remainder of this section.

2. Surface Circulation over the Continental Shelf During Periods of Open Water

   a) The large-scale circulation in Mackenzie Bay.

   b) The convergence north of the Mackenzie Delta, (in particular off Richards Island).

   c) Details of the circulation in Kugmallit and Liverpool Bays.

   d) The relatively strong northwesterly current off Herschel Island.

   e) The response of wind-driven surface currents both to the generating wind (especially that from the northwest) and to the relaxation of that wind.

   f) Dynamics of the eddies.

3. Subsurface Circulation over the Continental Shelf

   a) The mechanism(s) endowing the near-bottom current with its primary characteristics during the period approximately May through September: its position and its persistent northeasterly direction.

   b) The existence and characteristics of this current throughout the remainder of the year.

   c) The characteristics of mid-depth currents over the shelf throughout the year.

4. Circulation Within the Relatively Shallow Inshore Waters of the Southeastern Beaufort Sea Coast

   a) The characteristics of the water movements at all depths within the major coastline features - such as bays, lagoons and estuaries - during the open-water season.

5. Storm Surges

   a) The need for further extensive and intensive synoptic data on the characteristics of actual surges (primarily the positive variety), to provide verification and/or improvement of predictive numerical models that have been developed.

   b) Accurate information about the winds accompanying the surges.

6. Water Waves

   The verification and/or improvement of predictive models for wave characteristics (e.g., height, length and period) in both shallow and deeper water; these demand:

   - Highly accurate bathymetric mapping of the continental shelf and slope.

   - Extremely reliable generating-wind data throughout the Beaufort Sea area.

   - The effect upon wave formation of a generating fetch clear of unified pack ice, but containing isolated floes (in varying concentrations both in time and in space).

7. The Mackenzie River Flow

   a) Monitoring of the flow within the lower reaches of the river - in particular north of Aklavik and Inuvik, about 150 km south of the seaward edge of the Delta.

   b) The movement of the river water under the shorefast ice during the winter.

   c) The nature and amount of the suspended sedimentary material borne by the river throughout the year - especially during the large runoff period.

8. The Sea-Ice Régime

   a) Further more accurate data upon ice movement throughout the entire western Arctic, by means of both surface-based and remote (e.g., satellite) measurements.

   b) The characteristics of growth, decay and general behaviour of ice leads; more complete time-dependent data upon the shearing motions associated with rectilinear leads.

   c) Movements of ice floes near the coast.

d) Meteorological models of surface winds and pressures, to supply information upon surface stresses experienced by ice.

9. Water Turbidity or Transparency

a) Further information upon the seasonal variability in turbidity.

b) The degree to which mechanisms such as bottom currents, surface waves and internal waves contribute to the formation of near-bottom maxima in turbidity.

c) The degree to which mechanisms such as vertical stratification contribute to the origin of mid-depth maxima in turbidity.

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REFERENCES

Throughout this article, no specific reference has been made to the sources of the material utilized in its preparation. However, it has drawn heavily upon numerous reports, articles and papers. The majority of these have been technical reports produced during the course of the Beaufort Sea Project, but several works not specifically related to the project have also provided invaluable information to the article, especially to the sections dealing with general background. A list of the primary contributions follows. It may be noted that each of these contributions in turn contains extensive lists of references to previous work upon the general topic with which it deals.

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APPENDIX A

CONVERSION FACTORS: METRIC-TO-BRITISH AND BRITISH-TO-METRIC

Length	μ	cm	m	km	in	ft	mi	nmi
1 micron (μ) =	1	10^{-4}	10^{-6}	10^{-9}	$3.937(10^{-5})$	$.0328(10^{-5})$		
1 centimetre (cm) =	10^4	1	10^{-2}	10^{-5}	.3937	.0328	$6.214(10^{-6})$	$5.400(10^{-6})$
1 metre (m)=	10^6	100	1	10^{-3}	39.37	3.28	$6.214(10^{-4})$	$5.400(10^{-4})$
1 kilometre (km) =	10^9	10^5	10^3	1		3281	0.6214	.5400
1 inch (in) =	$2.54(10^4)$	2.54	0.0254	$2.54(10^5)$	1	0.083	$1.06(10^{-5})$	$0.92(10^{-5})$
1 foot (ft) =	$30.48(10^4)$	30.48		$3.048(10^{-4})$	12	1	$1.893(10^{-4})$	$1.646(10^{-4})$
1 statute mile (mi) =		160,434	1609.34	1.60934	63360	5280	1	0.868
1 nautical mile (nmi) =		185,200	1852	1.852		6076.1	1.15	1

1 fathom = 6 ft = 2 yards (yds) = 1.83 m

Area	cm^2	m^2	in^2	ft^2
1 square centimetre (cm^2) =	1	10^{-4}	0.1550	$1.076(10^{-3})$
1 square metre (m^2) =	10^4	1	1550	10.764
1 square inch (in^2) =	6.452	$6.452(10^{-4})$	1	$6.944(10^{-3})$
1 square foot (ft^2) =	929.03	$9.290(10^{-2})$	144	1

1 square mile (mi^2) = 27,878,400 ft^2 = 640 acres
1 acre = 43,560 ft^2
1 hectare = 10,000 m^2 = 2.471 acres

Volume	cm^3	m^3	in^3	ft^3
1 cubic centimetre (cm^3) =	1	10	0.06102	$3.531(10^{-5})$
1 cubic metre (m^3) =	10^6	1	$6.102(10^4)$	35.31
1 cubic inch (in^3) =	16.39	$1.639(10^{-5})$	1	$5.787(10^{-4})$
1 cubic foot (ft^3) =	$28.317(10^3)$	$2.832(10^{-2})$	1728	1

1 acre-foot = 43560 ft^3 = 1233.48 m^3

Speed	cm/sec	km/hr	ft/sec	kt(nmi/hr)
1 centimetre/second (cm/sec)=	1	0.036	0.0328	0.0194
1 kilometre/hour (km/hour)=	27.78	1	0.911	0.54
1 foot/second (ft/sec)=	30.5	1.10	1	0.592
1 knot(kt)=1 nautical mile/hour (nmi/hr)=	51.5	1.85	1.69	1

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DESIGNING, BUILDING AND MAINTAINING THE LANGARA POINT TSUNAMI WARNING STATION 1968-1980

by

R.E. Brown

INSTITUTE OF OCEAN SCIENCES
Sidney, B.C.

For additional copies or further information please write to:

Department of Fisheries and Oceans

Institute of Ocean Sciences

P.O. Box 6000

Sidney, B.C. CANADA

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ABSTRACT

A tide gauge station was established at Langara Point on Langara Island near the lighthouse on the 22nd of April, 1969. It was incorporated into the Pacific Tsunami Warning System as an active participant on 26th October, 1973, after much experimentation with instrumentation before suitable components were found that would meet the requirements and would survive the rigours of the North Coast.

It is hoped that the addition to the network of this strategically located station will help to prevent loss of life and property in the future.

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1. INTRODUCTION

On March 27 - 29, 1964, there occurred a severe Tsunami on the West Coast of Canada resulting in large property losses but no loss of life. This prompted Mr. G.C. Dohler, Head of Tides and Water Levels in Ottawa and Mr. S.O. Wigen, Regional Tidal Superintendent, Pacific Coast, to press for Canada's active involvement in the Pacific Tsunami Warning System.

Mr. W.J. Rapatz of Tides and Currents and Messrs. Christensen, Simms and Waroway from Water Survey flew by helicopter to Langara Island from Prince Rupert on July 10, 1968, to survey the site and determine the feasibility of establishing a Tsunami warning station there (Figures 1, 2, 3 and 4).

Two suggestions were put forth. The first one was to drill a large diameter, 25 foot deep, hole in the bedrock at a suitable site near the boat house. This hole would accommodate two stilling wells, one for the tide gauge and the other for the tsunami gauge. The instrumentation would be housed in a reinforced concrete structure over the stilling wells. The second suggestion was to construct a 2 to 5 ton reinforced concrete box with a stainless steel top, to house a pressure transducer which would be connected to a recorder at the lighthouse by means of a submarine cable and landline. Once assembled the box would be transported by boat then lowered to the ocean floor at a predetermined site.

After a thorough evaluation it was decided to proceed with the transducer proposal as it would be equally effective, less complex and less costly.

To expedite the establishment of the station the responsibilities were divided: Water Survey in Vancouver would design and supply the transducer box (See Fig. 5), Tides and Water Levels in Ottawa would supply the instrumentation an Tides and Currents in Victoria would supply the shi and personnel to establish the tidal station. It was also proposed that Tides and Currents in Victoria would operate the gauge until it became fully operational, at which time the station would become a permanent gauge station and would then be transferred to the jurisdiction of Water Survey

in Vancouver. This transfer did not take place, but the gauge became part of the Pacific Tsunami Warning System and the responsibility for operating and maintaining the station remains with Tides and Currents.

2. INSTALLATION

On April 22, 1969, permission was received from Captain E. Harris, District Marine Agent, Department of Transport in Prince Rupert to proceed with the establishment of a tide gauge station on Langara Island. Mr. G. Wilkes, Senior Keeper there, would be the Gauge Attendant.

Between May 22 and 24, 1969, a servo-operated tide gauge was installed under the direction of Mr. W.S. Huggett, Hydrographer-in-Charge C.S.S. *Parizeau*, from Tides and Currents in Victoria. Assisting were Messrs. Christensen from Water Survey and Mr. D.P. Todoruk from Newport Diving both of Vancouver.

The transducer housing was placed by the divers in the predetermined site using a rubber raft (Figure 6). The housing was connected to the shore with a submarine cable within a rubber hose and the seaward end was connected to the transducer by a waterproof connector. Approximately 650 sacks of specially packed concrete were placed over the hose between datum and the transducer housing. Above low water the cable was covered with concrete (Figure 7). The submarine cable was then connected to the servo-operated Ott Punch-Tape recorder by landline.

The installation had to be left incomplete because of prior ship and personnel commitments.

Messrs. G.C. Dohler and H. Thurm from Tides and Water Levels in Ottawa went to Langara Island in June 1969, to complete the installation of the servo-operated system.

3. OPERATION

Continuous problems with the punch tape gauges and the replacements plagued the operation until May 5, 1970, when Mr. W. Zubrycky from Tides and Water Levels

in Ottawa and Messrs. R.E. Brown and T. Soutar arrived on site and determined that the malfunction was due to salt water leaking into the transducer. Lacking materials they were unable to repair the transducer at that time. However, they did make a thorough survey to locate a suitable site where the tide gauge transmitting antenna could be installed.

On the return flight from Langara Island a stop was made at Digby Island where Mr. Zubrycky arranged with the Department of Transport to install a radio receiver and recorder.

4. ADDITION OF RADIO LINK

The project on Digby Island consisted of erecting a receiving antenna on a hill-top site and connecting it to two nearby radio receivers, then by landline to a Hagenuk Receiver and recorder in the airport terminal building. This undertaking was started on July 17, 1970. In rain and more rain the operation was completed at 20:30 hours on the 19th.

Two divers from Newport Diving in Vancouver joined the party in Prince Rupert, sailing to Langara Island on the lighthouse tender C.C.G.S. *Alexander MacKenzie* on July 20, 1970.

It was decided to divide the personnel into two crews: the larger one to assemble, erect and secure the antenna to the lighthouse. This phase was completed on schedule but it proved a most arduous job with the equipment available, in this case a one inch electric drill. The concrete in the lighthouse, built 1911, was 12 inches thick and very hard.

The second crew, including the divers, concerned themselves with repairing the transducer and cable. Investigation showed the heavy hose covering the submarine cable to be severed at one of the joints and the transducer housing full of sand and silt (Figure 8). The divers managed to clear the sand and silt with a water pump. The original transducer (Figure 9) along with the faulty cable was removed and replaced with a new 500 foot length of submarine cable and a new stainless steel transducer. Many sacks of special concrete mix were placed over the submarine cable between the transducer and low water by the divers to

protect the cable. The divers having completed their part of the project then departed by ship.

Between July 23rd and 26th, the remaining four crew members with assistance from the light keepers completed the following projects:

a) Ready-mix concrete was hand mixed and spotted along the transducer cable between low and high water. The first time this was unsuccessful, and did not harden but the second time liquid accelerator was used with satisfactory results.

b) New submarine cable was spliced to landline, 1000 feet of cable above high water was re-routed to prevent future damage, entire cable was inspected and repaired where necessary, all the cable was attached at regular intervals along the 5/8 mile of roadway.

c) Extra anchor bolts were fitted to the antenna and heavy guy wires were added for extra strength.

d) A co-axial cable was attached to the antenna and led into the transmitting room.

e) All other units including the servo-operated Hagenuk Punch Tape gauge and two radio transmitters were assembled, erected, tested and installed.

While Messrs. Zubrycky and Brown were on Langara Island other tranducer sites and methods were investigated, but later all proposals were rejected.

On, Sunday, 26 July, the party of four left the north coast of Langara Island by chartered float plane, an ocean take-off with heavy ground swell, not to be recommended for future trips.

On July 27, 1970, the radio receivers were checked on Digby Island and the Hagenuk Recorder was set in operation. The following day Mr. C. Smith of the Department of Transport suggested that Mount Hays might provide a better receiving site. Arrangements were made

for Mr. Zubrycky to go up Mount Hays with B.C. Telephone Company personnel and test the strength of the radio signal. These tests confirmed that Mount Hays was a better site than Digby Island for the receiving antenna.

On October 16, 1970, Langara equipment failed again.

November 17, Messrs. Zubrycky and Holdsworth from Ottawa and Mr. Brown landed at Langara Island from C.C.G.S. *Alexander MacKenzie*. During landing operations a considerable amount of gear, tools, instrumentation and test equipment was lost in an accident with the workboat. Three seamen were injured as well. The project at Langara was abandoned for the time being and the injured along with Messrs. Zubrycky, Holdsworth and Brown were flown to Prince Rupert.

On November 19, the first Langara receiving antenna was built on Mount Hays (Figure 22).

The next day Messrs. Zubrycky and Brown returned to Langara Island. The transducer and the cable were checked and were found to be faulty. The low-powered Motorola Transmitter was tested and found to be operating satisfactorily.

5. Waterfront Reconstruction

Many suggestions were made to modify the Langara installation and all these suggestions were thoroughly investigated. After consideration of all the alternatives the following modifications were made:

a) A 1 1/2 inch diameter hole approximately 200 feet long was drilled through bed rock, starting above high water and exiting seaward at a point approximately 10 feet below datum.

b) The transducer cable was run from a weather-proof shore junction box through the drill hole and thence along the ocean floor to the transducer housing and transducer.

c) The transducer was housed on the top of the concrete transducer housing in a new stainless steel cage designed by Mr. Brown (Figure 10).

The actual waterfront construction took place on Langara Island between September 20 and 30, 1971. Mr. Brown was the co-ordinator of the project, responsible for indicating to the drillers where the hole was to start in the rock and the vertical and horizontal angles at which the hole was to be drilled. All the electronic and radio work was the responsibility of Mr. Thurm.

All the personnel and gear were transported to Langara Island by the lighthouse tender C.C.G.S. *Alexander MacKenzie*, courtesy of the Ministry of Transport.

A 151 foot 1-1/2 inch diameter hole was drilled in bed rock from a pre-selected point above high water, exiting seaward 6 1/2 feet below datum (Figures 15 and 16). The drilling was carried out by Messrs. M. Chase and A. Helfrick from Inspiration Drilling. It was necessary to blast a trail through the woods to get the drill rig to the site.

The divers removed the old submarine cable and transducer, resacked cement, surveyed a route for the new submarine cable, cut seaweed, and drilled holes for securing 10 strip anchors to anchor cable to the sea floor. The submarine cable between the drill exit hole and the transducer housing was covered with 200 sacks of special concrete mix (Figures 19, 20, and 21). The transducer was connected to the submarine cable and placed within the stainless steel cage on top of the tranducer housing. The key to the whole operation was Mrs. Wallace, wife of the senior light keeper, who prepared excellent meals and between-meal snacks and timed them to match the project perfectly.

Messrs. Thurm and Brown went to Mount Hays on October 1st to check the antenna (Figure 22) and the Langara radio receivers and then on to Digby Island to connect the Hagenuk recorder and instruct the temporary gauge attendant.

The over-all cost of this particular project amounted to $16,000.00 plus transportation and other contributions made by the Ministry of Transport.

Word was received in the Victoria office on October 14, 1971, from the Ministry of Transport on Digby Island advising the Victoria office that the Langara record was showing uncontrolled fluctuations.

Mr. Zubrycky travelled to Langara Island on November 15th by chartered float plane, landing on the lake and walking overland to the lighthouse with limited gear. The on-site inspection revealed two problems:

a) Malfunction of the telemetry module.

b) An intermittent open curcuit in the transducer or lines.

This showed that the present installation was going to continue to be expensive to maintain and alternatives again were investigated. One suggestion by Mr. Zubrycky was to construct a stilling well in the cut by the lighthouse; a suggestion which had to be ruled out due to construction dangers and other considerations.

The lighhouse keeper had one major complaint about our installation. The radio transmitter was blocking out his TV reception. Since this is a serious matter indeed, in such an isolated spot, it was investigated and eventually fixed to his satisfaction.

6. A MAJOR STORM ON LANGARA ISLAND

A severe storm struck Langara Island on January 27, 1972, when winds blew steadily for hours from the west at 85 m.p.h. The doors and windows on the west side of the lighthouse engine room were blown in. Salt spray came over the helicopter landing site 150 feet above sea level and into the cisterns in the houses, contaminating the drinking water. The same storm severely damaged the lighthouse wharf landing site.

Photographs show the area before and after the storm (Figures 11, 12, 13, and 14).

Although it will never be known for certain it is felt that this storm finished the already damaged submarine sensor link.

A new transducer, a telemetry module, servo-operated punch tape recorder, wiring jig and test plug were obtained from Ottawa and shipped to the site.

Three divers from Newport Diving joined the lighthouse tender C.C.G.S. *Sir James Douglas* on April 4, 1972, in Prince Rupert and sailed to Langara Island.

On April 5th, Messrs. Brown and Soutar flew to Langara by chartered Beaver aircraft and it was so calm the pilot was able to land the aircraft on the sea near the ship.

An investigation by the divers revealed that there was no trace of the 2 to 5 ton reinforced concrete transducer housing (Figure 5). Only the flat stainless steel plate that covered the first installation was left on the sea floor where the structure had been. In addition, 2 of the 10 pairs of brass lag bolts, 50 feet of broken transducer cable and 3 of 200 sacks of concrete were recovered, nothing more.

When the transducer was installed in the cage on the top of the transducer housing there was a very heavy marine growth (Figure 16). In April the sea bottom was absolutely clear and rocks up to 4 1/2 tons had been moved like marbles.

As a storm was building up and nothing further could be done at this time the instruments and materials for the gauge station were left at Langara Island. The repair team was taken back to Prince Rupert on C.C.G.S. *Sir James Douglas*.

The B.C. Telephone Company was advised on April 14, 1972, to discontinue the service of the telephone landlines from Mount Hays to Digby Island until the telemetry system on Langara Island could be re-activated.

Between June 5th and August 9th, discussions were held and an on-site investigation was made by Messrs. Allon and Waroway of Water Survey and Mr. Brown. The following alternatives were put forward for re-activating the Langara Telemetry system.

a) Drill a 5 inch diameter hole in the bed-rock by the lighthouse.

b) Use the existing diamond drill hole for a nitrogen bubbler system.

c) Drill a larger and longer hole, 300-700 feet long, in bed rock near the existing hole but into deeper water.

d) Drill a hole 300 foot long seaward of the existing hole at a predetermined site. The exit of this hole to be about 22 feet below datum.

It was decided to use the existing diamond drill hole for a nitrogen bubbler system on a trial basis. Again, this was a co-operative project by the same three sections of the Department of Environment.

7. The Second Waterfront Reconstruction

A six foot square metal building to house the bubbler gauge and ancillary equipment, was constructed near the transducer cable junction box (Figures 18 and 24). The work was done by Water Survey.

During January and February, 1973, several attempts were made to get a technical and construction crew to Langara, in order to install the bubbler system and a new tide scale, and to carry out the necessary levelling. Finally, after many delays and cancellations due to weather, installation of the bubbler system commenced on February 24th.

The bubbler system, including the back-up Ottboro recorder, was assembled, connected and tested. For details of the Langara Island water level telemetry system (with gas purge system), and site plan, refer to Langara Island Tide Gauge site, to block diagram transmitting site and block diagram receiving site (Figures 17, 50 and 51).

The transmitting antenna and its bracket were bolted securely to the lighthouse (Figures 26 and 27). In addition cables were attached between the antenna and the lighthouse to limit the movement in the bracket.

On a trial basis, a Versilite tide staff was attached to the vertical face of a concrete culvert originally used for the old boat ramp, the only such vertical face available. The concrete proved to be of poor quality and the anchors soon pulled out, leaving another problem to solve.

The telemetry equipment was repositioned in the Radio Room of the power-house and a separate fuse panel was set up for this equipment exclusively. All components including the radio transmitters were connected and tested and the senior light keeper was instructed in the operation of the equipment and hired as the gauge attendant.

The landline was repaired where it had broken, and re-routed at the seaward end to make it less vulnerable.

Before the party left Langara Island a complete telemetry systems check was carried out, consisting of the following:

a) Checking the nitrogen bubbler system including quantity of nitrogen remaining, nitrogen pressure to the system, and number of bubbles per minute.

b) Checking the manometer for smooth operation and correct heights. (When applicable.)

c) Checking the time, height and the correct trend on the Hagenuk recorder.

d) Doing several simultaneous height comparisons between the tide scale, manometer and Hagenuk recorder.

e) Checking the output signal from the telemetry radio transmitter using a headphone.

f) Doing a visual check of the landline for cuts, breaks and abrasions.

g) Checking the transmitting antenna for loose bolts or guy wires and the connecting cable for damage or poor connections.

On March 28, 1973, arrangements were made and a contract was signed whereby the Ministry of Transport personnel in Prince Rupert would service and maintain the electronic phase of the Tsunami Warning Gauge complex on Langara Island, Digby Island and Mount Hays. A portable 5 watt Motorola transmitter was obtained and shipped to Digby Island on May 15. This unit still is being used to test the Mount Hays radio receivers for the Langara telemetry system.

It was considered that the bubbler building, although situated quite high above sea level, was still endangered by heavy storms, and plans were made to construct a reinforced concrete buffer wall to protect its vulnerable corner.

Mr. Brown, assisted by casual labour, carried out the following work between July 28th and August 15th:

a) Anchored a new Versilite tide scale to the vertical face of the concrete culvert for the old boat ramp.

b) Established new bench marks and written descriptions.

c) Searched to try to locate the diamond drill hole seaward exit. Even at a predicted -0.5 foot tide the exit hole could not be seen although the nitrogen bubbles were readily visible (Figure 16). Without a diver it is impossible to identify positively the location of the hole.

d) Carried out levelling between the bench marks, tide scale and tentative location of the diamond drill exit hole.

e) Concrete blocks, concrete, reinforcing rods, rock drill and tools were transported by hand through the woods to the bubbler building site. Built buffer wall using a great deal of reinforcing rod (Figure 25). It was hoped that the addition of this wall would prevent damage to the building in the event of a storm.

f) Checked the telemetry system thoroughly.

g) Wrote detailed gauge operating instructions for the gauge attendants.

h) Removed the rusty hoisting brackets for the bubbler building, replaced, caulked and painted the bolts.

i) Painted indicator lines along the plank roadway to show where the landline was located.

j) checked the bubbler system and adjusted the bubble rate.

8. LANGARA POINT TIDE GAUGE STATION JOINED PACIFIC TSUNAMI WARNING NETWORK ON OCTOBER 26, 1973

When Langara Island became part of the Pacific Tsunami Warning Network all messages were relayed through H.M.C. Dockyard, plus other relay stations, to Hawaii. This method of communication was very frustrating and time consuming with lengthy delays.

Mr. Roy Coan, Tele-Communications Area Manager at the Prince Rupert Airport received permission to contact P.T.W.C. in Hawaii and set up a direct teletype link. This link was completed in December 1973. To this day it has proven to be one of the most efficient in the warning net. This link consists of:

> Telemeter from Langara Island to Digby Island (Prince Rupert) Communication Station.
> Thence teletypewriter via A.F.T.N. to P.T.W.C.

Between January and August 1974, problems ocurred at the station:

> A severe snow storm shorted out the transducer terminals in January. This problem later corrected itself, but nevertheless a vented plastic box was fabricated to house the transducer, and installed by the lighthouse keeper to prevent any further re-occurrence.

In April, the power-supply unit failed and the staff gauge was washed away by a severe storm. Personnel from M.O.T. in Prince Rupert installed a new power-supply unit in the Langara telemetry system in mid-June, which enabled the system to be re-activated.

Continuous problems with the loss of tide scales at Langara Island made it imperative to try some different approach, as height control was necessary if usable records were to be obtained.

Various fast drying paints were investigated which would meet the following requirements:

a) Adhere to rough concrete

b) Dry rapidly

c) Would not deteriorate after being immersed in salt water.

d) Would last at least a year.

Several stencils were cut in Victoria by Mr. Brown and sent to Langara Island for use on his next scheduled trip to the island.

Mr. Brown again went to Langara Island on August 19th, where he stayed and worked until August 30th. During this period the following projects were carried out:

a) Thoroughly cleaned, caulked and painted the bubbler building.

b) Cleaned and dried a section of the vertical face of the old concrete culvert for the boat ramp and then three tide scales were stencilled onto the concrete. They were marked separately "A", "B" and "C", and each was painted with a different kind of paint (Figure 23).

c) Established more bench marks and wrote up their descriptions. All bench marks and tide scales were levelled.

d) Put in cribbing then made and poured extra concrete to strengthen further the bubbler building buffer wall.

e) While Mr. Manly, the new Telecommunications Area Manager from Prince Rupert was on a routine inspection trip of the Langara Light Station, Mr. Brown explained the Langara Island telemetry system with all its idiosyncracies to him.

f) Repainted the lines along the roadway indicating the route of the landline.

g) Re-spliced many breaks in the landline.

M.O.T. personnel from Prince Rupert went to Langara Island on February 11, 1975, to recalibrate and reset the telemetry system to record on the proper scale. This project took 2 1/2 days.

In February 1975, the Langara receiving antenna on Mount Hays was damaged beyond repair by an ice storm. A temporary antenna was made by Mr. Manly and installed inside M.O.T.'s fibreglass tower on Mount Hays.

More trouble developed and on March 10th, M.O.T. technicians were dispatched to Langara Island to repair the telemetry system. One broken wire was found. This was repaired and the system was recalibrated, but a system check revealed there was a problem with the transducer. A replacement Conrac transducer was ordered. The Canadian cost then was $795.00, a good figure to remember. Since the old transducer was still serviceable, it was held as a spare.

Mr. Brown went to Langara Island on July 30th to carry out the annual gauge inspection, level and adjust the gauges, repaint the bubbler building, tide scales and landline route along the roadway. These projects took until August 11th.

In October the telemetry system again was out of order. M.O.T. technicians from Prince Rupert went to Langara Island on October 14th to replace the transducer and recalibrate the system, but they were unsuccessful in their efforts. Further investigation revealed that the junior light keeper had cut the landline in many places while clearing the roadway with a chain saw, necessitating the replacement of a large section of the landline. Though sufficient new cable was not available on the Island temporary repairs were made.

In December 1975, the Ottboro gauge on Langara Island was not recording the proper range.

Mr. Brown left Prince Rupert on February 19, 1976, for Langara Island, where the following work was carried out before his return to Prince Rupert on March 2nd.:

a) Replaced the Ottboro gauge.

b) Checked the Tsunami warning system.

c) Repainted the tide scales.

d) Levelled the bench marks and tide scales.

e) Range checked the tide gauges.

f) Serviced the Hagenuk recorder.

g) Checked and adjusted the bubbler system.

h) Instructed the gauge attendant in his duties. (By now Mr. C. Readhead had taken over as senior lightkeeper).

i) Surveyed and rerouted the landline between the lighthouse and respliced the cable where necessary. Two M.O.T. technicians assisted in these tasks. Figure 28 - Clearing the Roadway Langara - Winter 1976.

j) The telemetry system was checked thoroughly and recalibrated by the two technicians.

The transducer was sent to the Conrac Corporation in Duarte, California, for repairs and recalibration on March 15, 1976.

New CAUTION signs for marking the route of the landline were made up at the Prince Rupert Coast Guard Base and sent to Langara Island where they were mounted in appropriate places in April 1976 (Figure 29).

In June, technicians from M.O.T. in Prince Rupert installed the new uninterruptible power supply unit.

The temporary inside antenna on Mount Hays had to be replaced with a new Sinclair antenna, and receivers had to be switched to battery power. This was done in October. The landline between Digby Island and Mount Hays had to be repaired.

In March, 1977, new gears for the pen drive motors at Digby Island and Langara had to be manufactured.

In April, metric conversion parts and one measuring motor with ten-speed potentiometer were ordered at a cost of approximately $6,000.00.

On July 18th, Mr. Brown went to Langara Island and performed the following projects:

a) Secured a new plastic A.B.S. material metric tide scale to the vertical face of the old concrete culvert for the boat ramp. The scale

was secured to the concrete by using an electric Hilti drill and 32-3/8 inch Hilti-Kwik bolts (Figure 30).

b) Cleaned and repainted the two old tide scales and stencilled one new metric scale on the vertical face of the concrete culvert of the old boat ramp. The paint proven most satisfactory is BAPCO No. 33-799 white traffic paint (the paint used on highways).

c) Levelled the tide scales and bench marks.

d) Washed, cleaned and painted the bubbler building.

e) Replaced the clock on the Hagenuk recorder.

f) Checked the tide gauge and found it to be operating satisfactorily.

Mr. Brown returned to Prince Rupert on July 27th.

9. The Third Waterfront Reconstruction

On October 29, 1977, 80 foot high waves struck the west end of Langara Island. The wharf landing site and all storage tanks were washed away, the winch house was demolished, and the bubbler building was severely damaged (Figures 31, 32 and 33).

In November, Mr. Brown again travelled to Langara, taking with him casual labour from Prince Rupert, to assess the damage and effect necessary repairs.

The following work had to be carried out:

a) Cleaned, repaired and painted the bubbler building.

b) Installed a reconditioned transducer and Ottboro tide gauge.

c) Built a new roadway to the bubbler building site.

d) Re-wired the landline terminals and re-established the telemetry system.

f) Made a sketch to show how the buffer wall could be changed to give greater protection to the bubbler building.

Langara Island is pounded by storms frequently, many of them more severe than the illustration would indicate (Figure 34).

In December 1977, the transducer and electronics again malfunctioned; the Ottboro gauge was activated and the results confirmed the assumption. In January, the Langara telemetry system was recalibrated by M.O.T. personnel from Prince Rupert.

In April 1978, it was found that the radio link between Langara and Digby Island had failed again. A technician from M.O.T. was sent to Langara to repair the transmitter and install a modified pen drive gear. On the same date other technicians from Transport Canada installed the new antenna on Mount Hays (Figure 46).

In June, a reconditioned Ottboro gauge had to be shipped to Langara. At the same time the landline between the transducer and the lighthouse was found to be cut again. The gauge was installed and the landline repaired.

From a call made to the Conrac Corporation in California on July 7th, it was learned that the reconditioned transducer had been shipped to Sydney, Australia instead of Sidney, Canada, but it was now on the way back to Canada.

10. THE FOURTH WATERFRONT CONSTRUCTION PROJECT

It was considered that due to the expected winter storms, the severity of which we had finally begun to understand, further modifications had to be made to the gauge site. Therefore, Mr. Brown was sent to Langara again in July 1978, and between July 17th and August 9th, with the assistance of casual labour and the lightkeepers at Langara, carried out the following projects:

a) Excavated the new bubbler building foundation site and poured a reinforced concrete foundation.

b) Re-routed the bubbler tube from the shore end of the diamond drill hole to the new bubbler building site. This necessitated building a reinforced concrete wall to support the bubbler tube. The bubbler tube itself had to be within a larger tube and the entire line had to be encased in concrete on top of the wall and along the rock face, always being careful to maintain a slight gradient without dips or peaks.

c) Unbolted the bubbler building from the old site, constructed a temporary bridgework, lowered the building onto its face and moved it by block and tackle, bars, levers and rollers. Then hoisted the building onto the new foundation with timber and metal levers and block and tackle, and bolted it in place at the new site (Figures 35 to 38 inclusive).

d) Dug a drainage system around the bubbler building (Figures 39 and 40).

e) Built a bridge to the bubbler building.

f) Cleaned and painted the bubbler building.

g) Cemented extra rocks around the bubbler tube wall.

h) Checked the Ottboro and Hagenuk gauges.

i) Re-established the bubbler system.

j) Installed the uninterruptible power-supply unit.

k) Checked and re-secured the landline along the roadway where necessary.

l) Levelled the bench marks and tide scales.

Figures 41, 42, and 43 - Various views of the bubbler building.

In November the Langara bubbler system was not operating.

Mr. Brown travelled again to Langara, replaced nitrogen valves, converted the Hagenuk recorder to metric and with the assistance of an M.O.T. technician replaced the transducer and carried out a systems check.

Through the years 1979 and 1980 still many problems were encountered with the Langara Tsunami station, but by then we had learned to respond quickly and for the most part the station operated satisfactorily. Some of the problems encountered in the last few years may be of interest:

Late in 1978 it was found that the recorder was not functioning normally. After much investigation it was learned that under certain atmospheric conditions our transmission had interference from about 40 base and 800 mobile units of the Tennessee Valley Power Authority. Naturally, our transmissions also interfered with their operations. We reduced the power of our transmitter, but finally, in June of 1980, had to change frequency, which solved the problem.

Langara Island has been plagued with transducer problems. After the most recent transducer was replaced with the reconditioned spare the faulty unit was sent to the Conrac Corporation in California for repair and recalibration.

When it was learned that the transducer had been lost the Conrac Corporation was contacted and they advised that the replacement cost of this transducer (1975 cost $765.00) would now be $1,600.00, with a delivery time of 180 days.

When contacted the carrier offered to compensate the Department for the loss of the transducer at the rate of $10.00 a pound, about the weight of the transducer. As we were not satisfied with such an agreement the matter was turned over to the Canadian Justice Department.

Later in the year the Conrac Corporation advised the Department that the transducer had been located in the U.S. Customs in Duarte, California, but it could not be released to them until new customs clearances were

received from the Department as the in-transit time had exceeded the prescribed limits. To further complicate the matter the Department was asked to pay $197.00 for storage and $105.40 for search fees. Two sets of customs clearances were lost in the mail, but the third set finally arrived at its destination.

Sixteen months after shipment from Sidney the transducer was repaired, recalibrated and returned to the Department for a total cost of $500.00 which included the cost of repairs, search and storage charges. It was decided to pay the additional charges under protest.

A decision was made to install a manometer at Langara Island to improve the recorder height control. A manometer is much easier and more accurate to read than the water level on the tide scale especially when one considers that the sea is usually rough or there is a heavy ground swell at the site. There were several problems with the manometer but these were soon rectified and the unit has proven itself to be satisfactory and reliable.

Problems arose in the nitrogen system when the pressure suddenly increased beyond allowable limits. New regulator valves were installed, and later a pressure relief valve was installed in the system. This ended any danger of instrument damage in case of another nitrogen over-pressure.

For a better understanding of the entire telemetry system on Langara Island (Figures 44, 45, 47, 49, 50 and 51).

Over many years isolated, yet strategically located sites have been a challenge to many Government Agencies and Langara Island has been no exception. The first Langara Point light station was built in 1911. Then during the Second World War, a radar station was built at Radar Point and manned by the R.C.A.F. Along the plank roadway leading to Radar Point is the carving of a face in a standing cedar snag (Figure 52). This carving probably was done by one of the men from Radar Point.

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For a better understanding of the entire telemetry system on Langara Island (Figures 44, 45, 47, 49, 50 and 51).

Over many years isolated, yet strategically located sites have been a challenge to many Government Agencies and Langara Island has been no exception. The first Langara Point light station was built in 1911. Then during the Second World War, a radar station was built at Radar Point and manned by the R.C.A.F. Along the plank roadway leading to Radar Point is the carving of a face in a standing cedar snag (Figure 52). This carving probably was done by one of the men from Radar Point.

SUMMARY

Although there have been many problems over the years with the telemetry system on Langara Island it is well established now and the station has taken its rightful place in the Pacific Tsunami Warning Network. Should there ever be a major Tsunami in the North Pacific it is hoped that the station located on Langara Island will help to prevent loss of life and property.

Without the wholehearted co-operation and support of Captain Edward Harris, District Manager, Transport Canada, Canadian Coast Guard Base in Prince Rupert and the various Tele-communications Area Managers at the Prince Rupert Airport and the help of so many of their staff this project never would have materialized.

ACKNOWLEDGEMENTS

Acknowledgements and thanks are due to people who have been most helpful. Mr. W. J. Rapatz gave suggestions and reveiwed this manuscript. Miss Tammy Lehman did the typing, Mrs. Barbara Smith, Messrs. Art Lyon, Alan Schofield and Malcolm Brown produced the graphics and Mr. Brian Watt has done the photographic work.

Copies of the following original drawings and photos have been included in this manuscript:

Figure 5 - Reinforced Concrete Transducer Housing - drawing by Water Survey, Vancouver.

Figure 6 - Tide Gauge Transducer Site - drawing by Water Survey, Vancouver.

Figure 8 - Silted Transducer Housing - underwater photo by David O. Todoruk, Newport Diving, Vancouver.

Figure 13 - Storm Damage to Engine Room - photo by Kenneth Wallace, Langara Point Light Station.

Figure 14 - Storm Damage to Wharf Landing Site - photo by Kenneth Wallace, Langara Point Light Station.

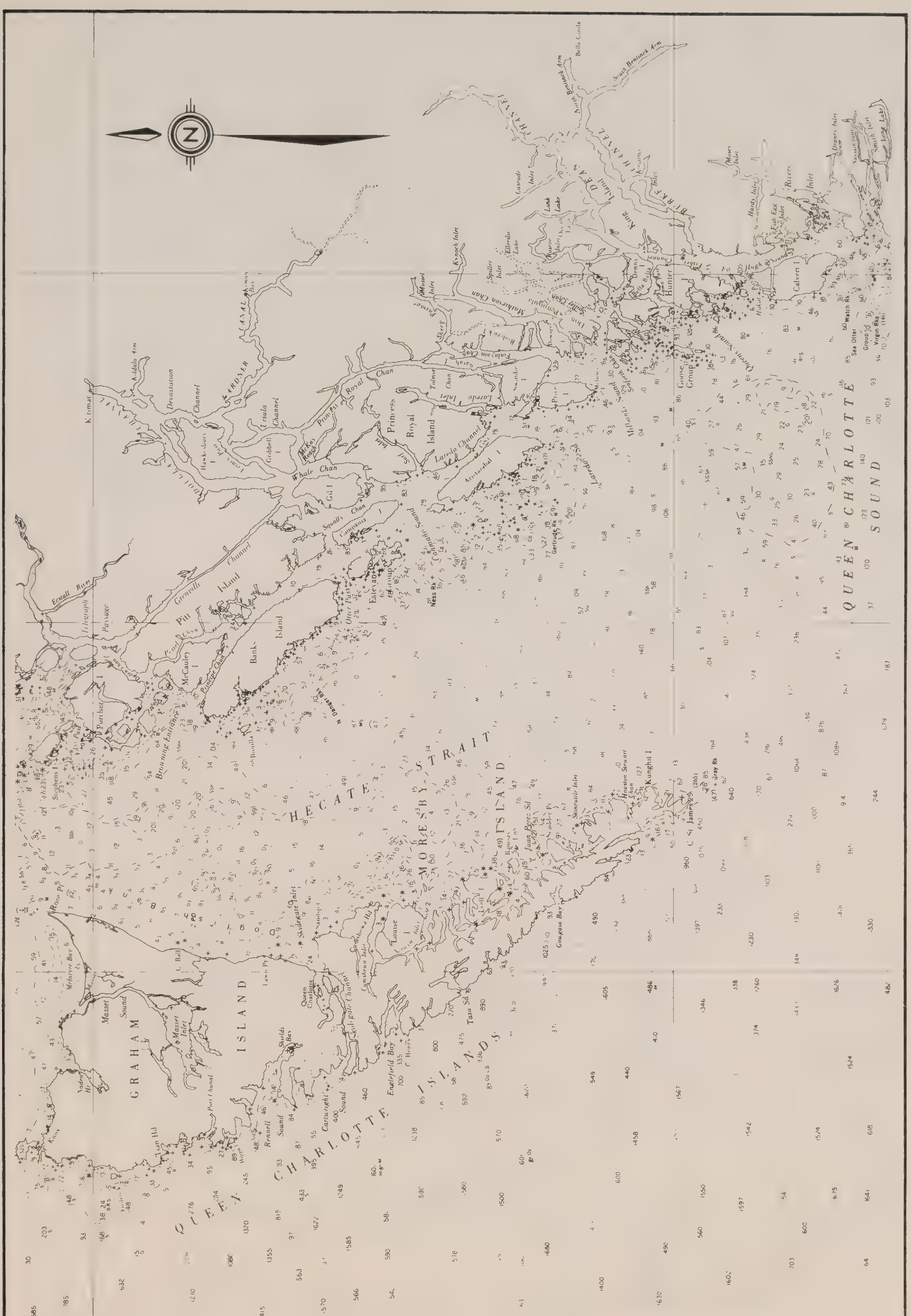


Figure 1 North Coast of British Columbia to Dixon Entrance

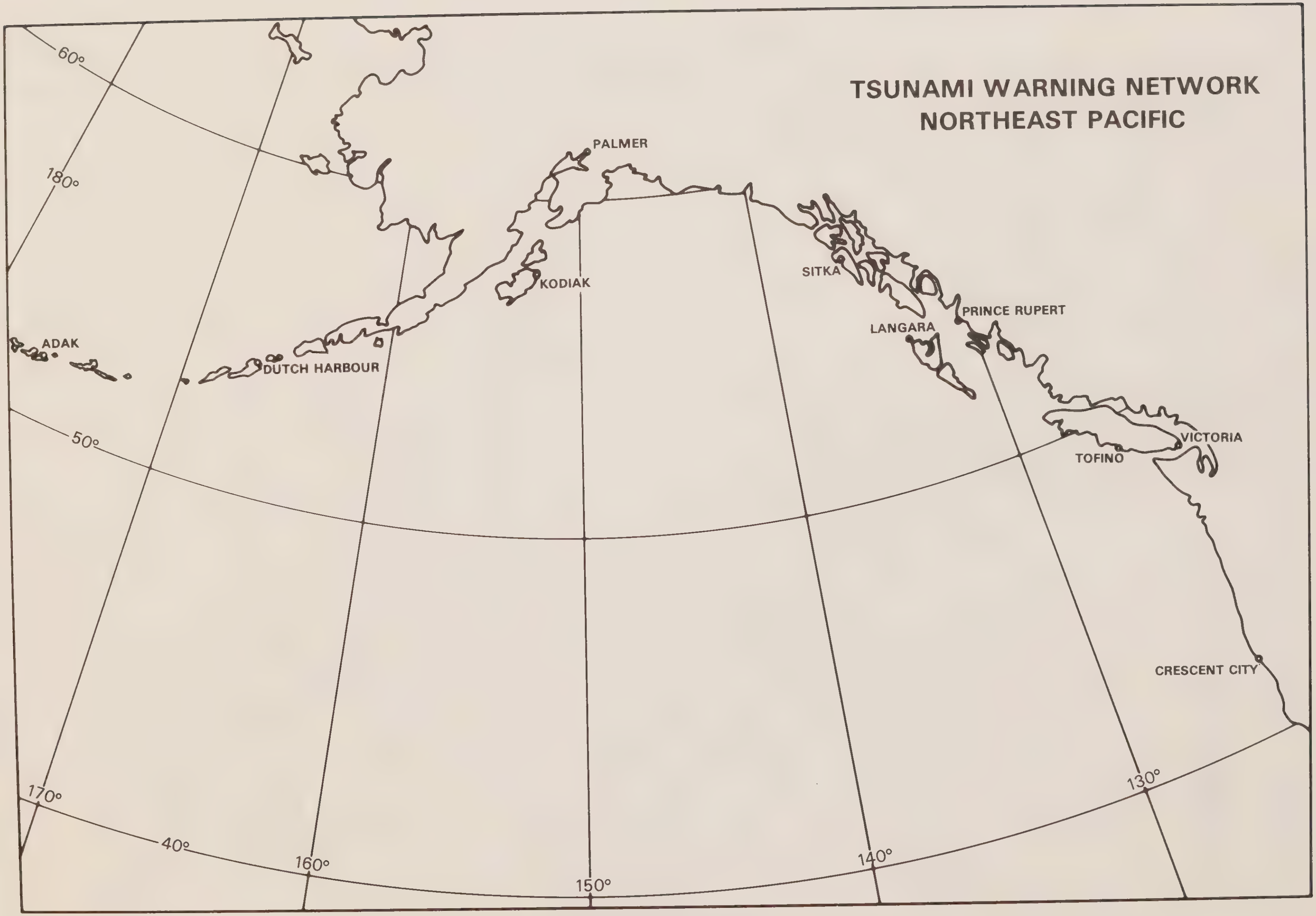
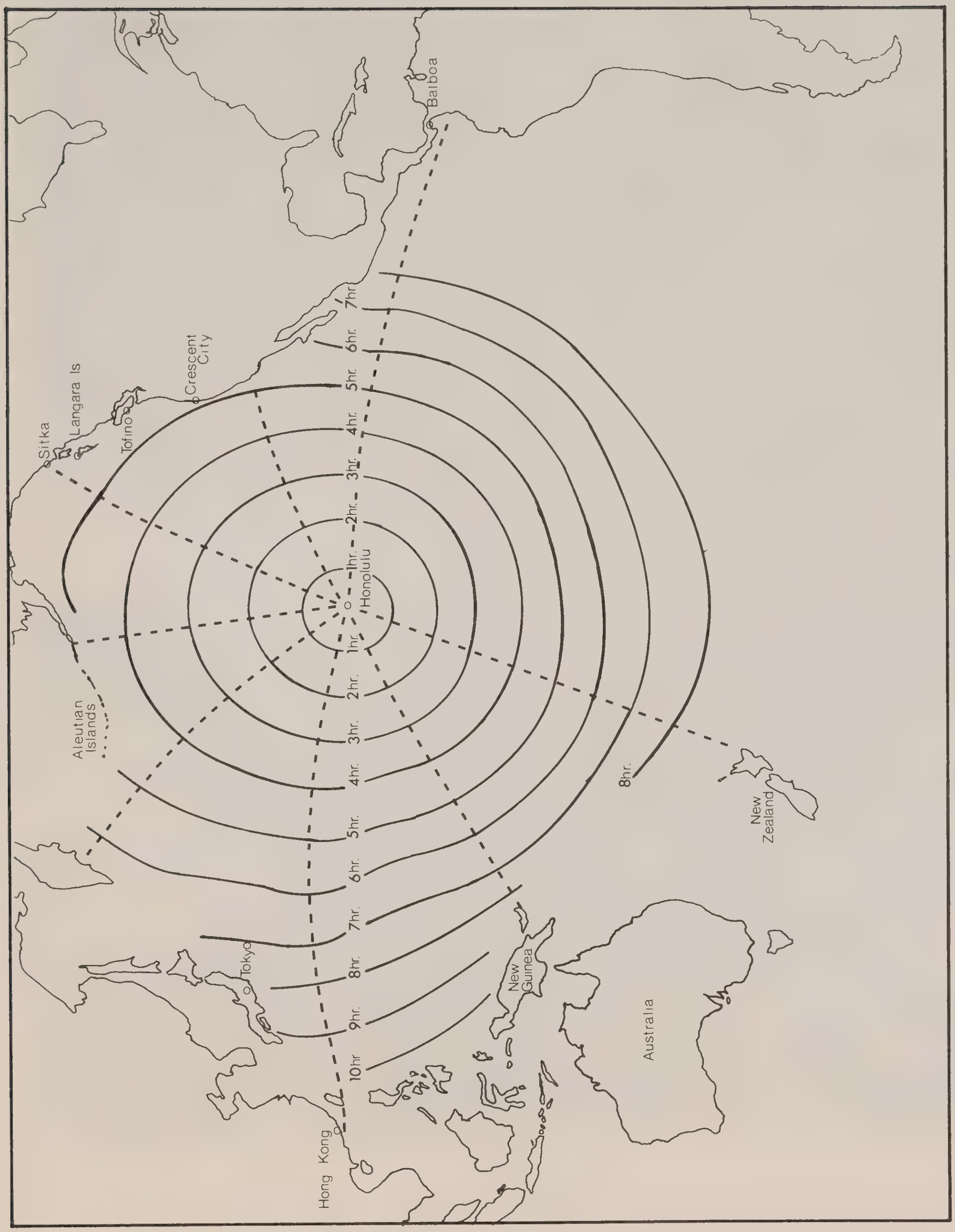


Figure 2

Pacific Tsunami Warning Network



Tsunami Travel Times to Honolulu

Figure 3

Langara Island
Figure 4

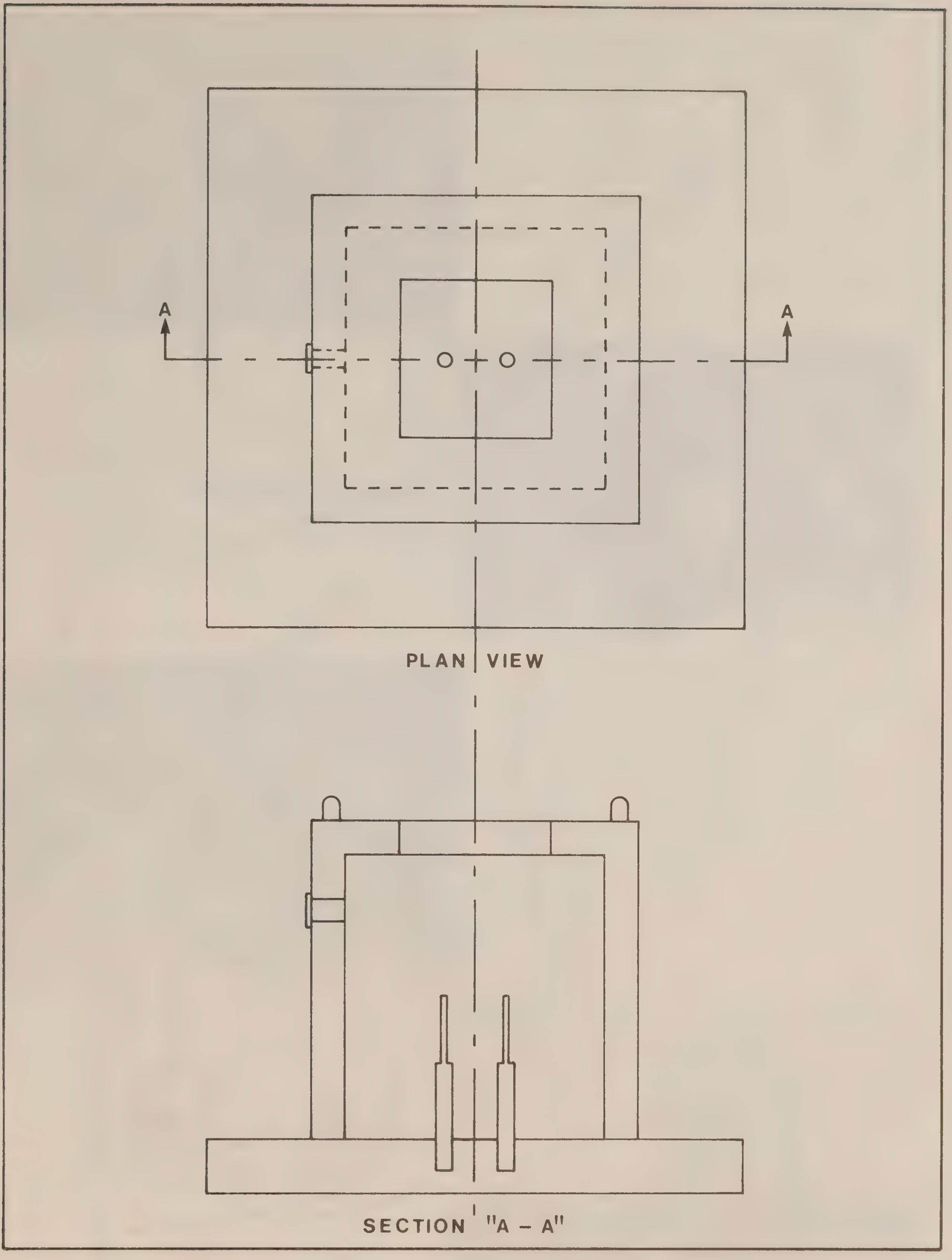


Figure 5 Reinforced Concrete Transducer Housing

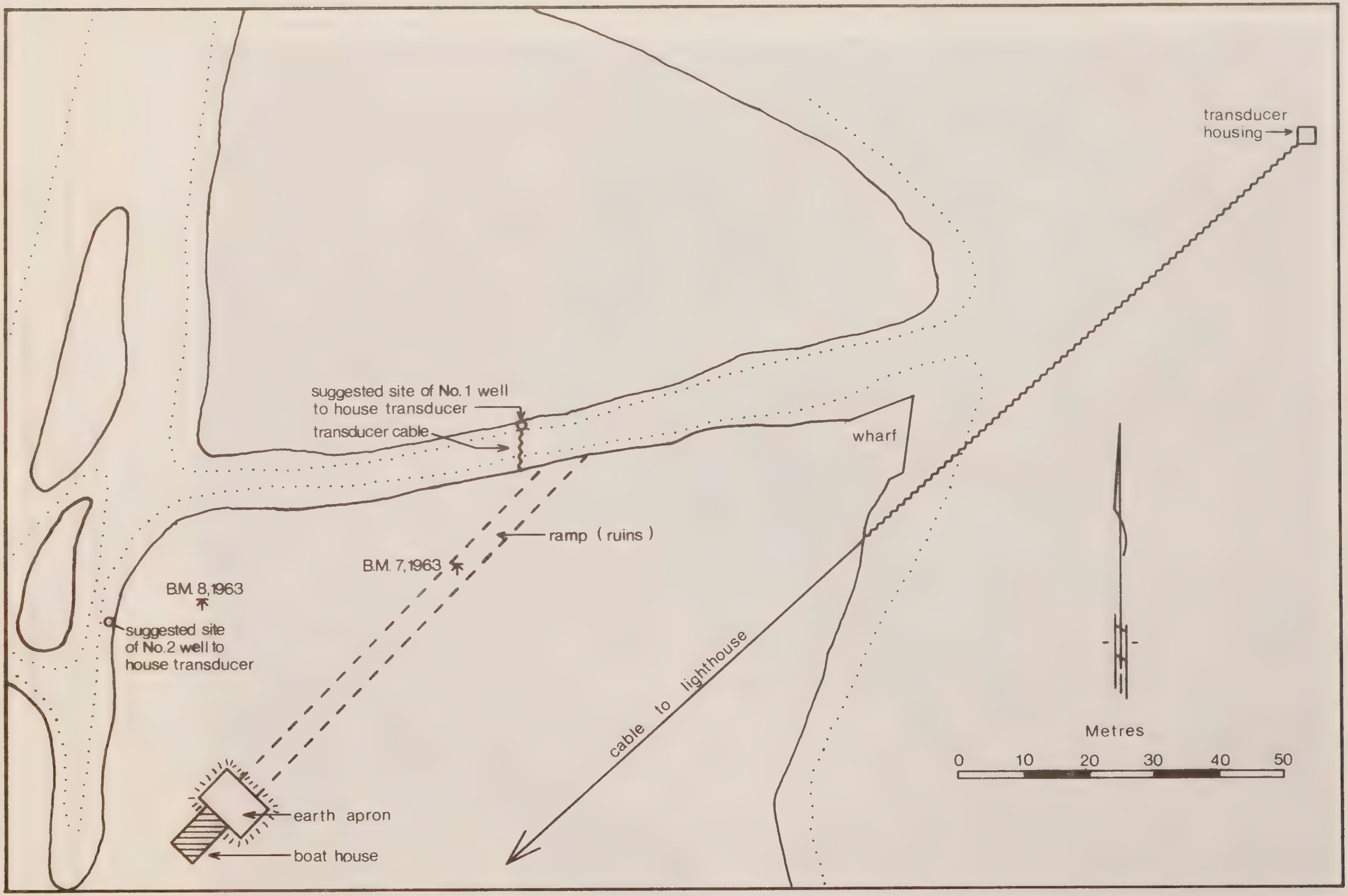
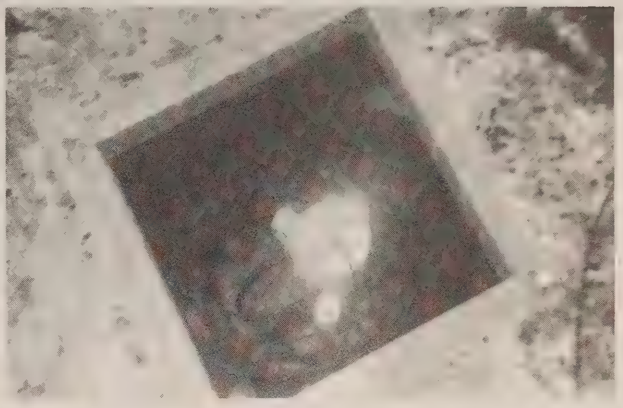


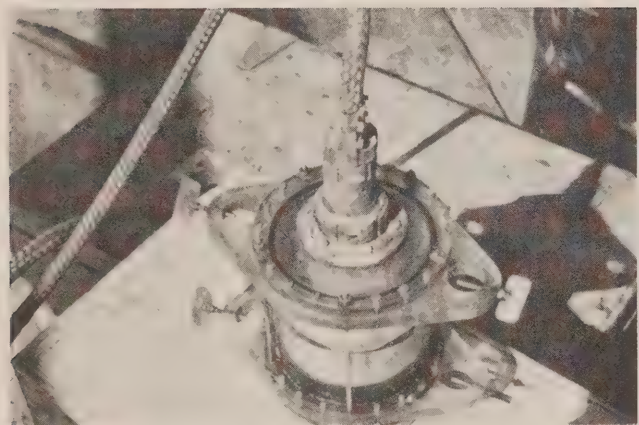
Figure 6

Tide Gauge Transducer Site

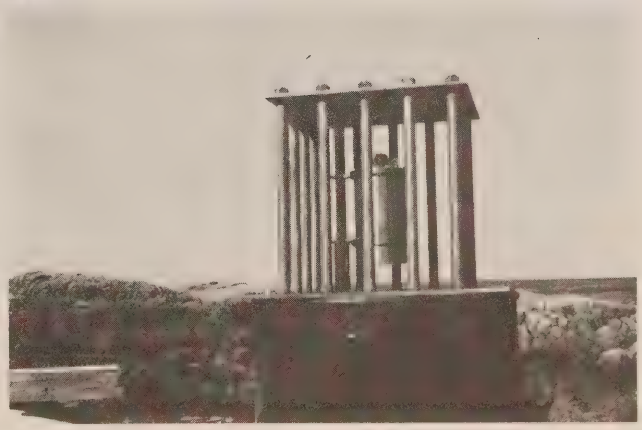
Concrete Over Transducer Cable
Figure 7



Silted Transducer Housing
Figure 8



Faulty Transducer
Figure 9



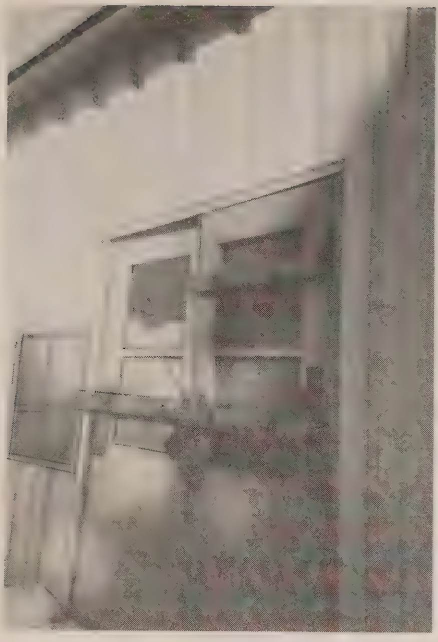
Stainless Steel Transducer Cage
Figure 10

Langara Point Light Station

Figure 11

Light–House & Engine Room

Figure 12



Storm Damage to Engine Room
Figure 13

Storm Damage to Wharf Landing Site
Figure 14

Diamond Drilling
Figure 15

Seaward Exit of Diamond Drill Hole
Figure 16

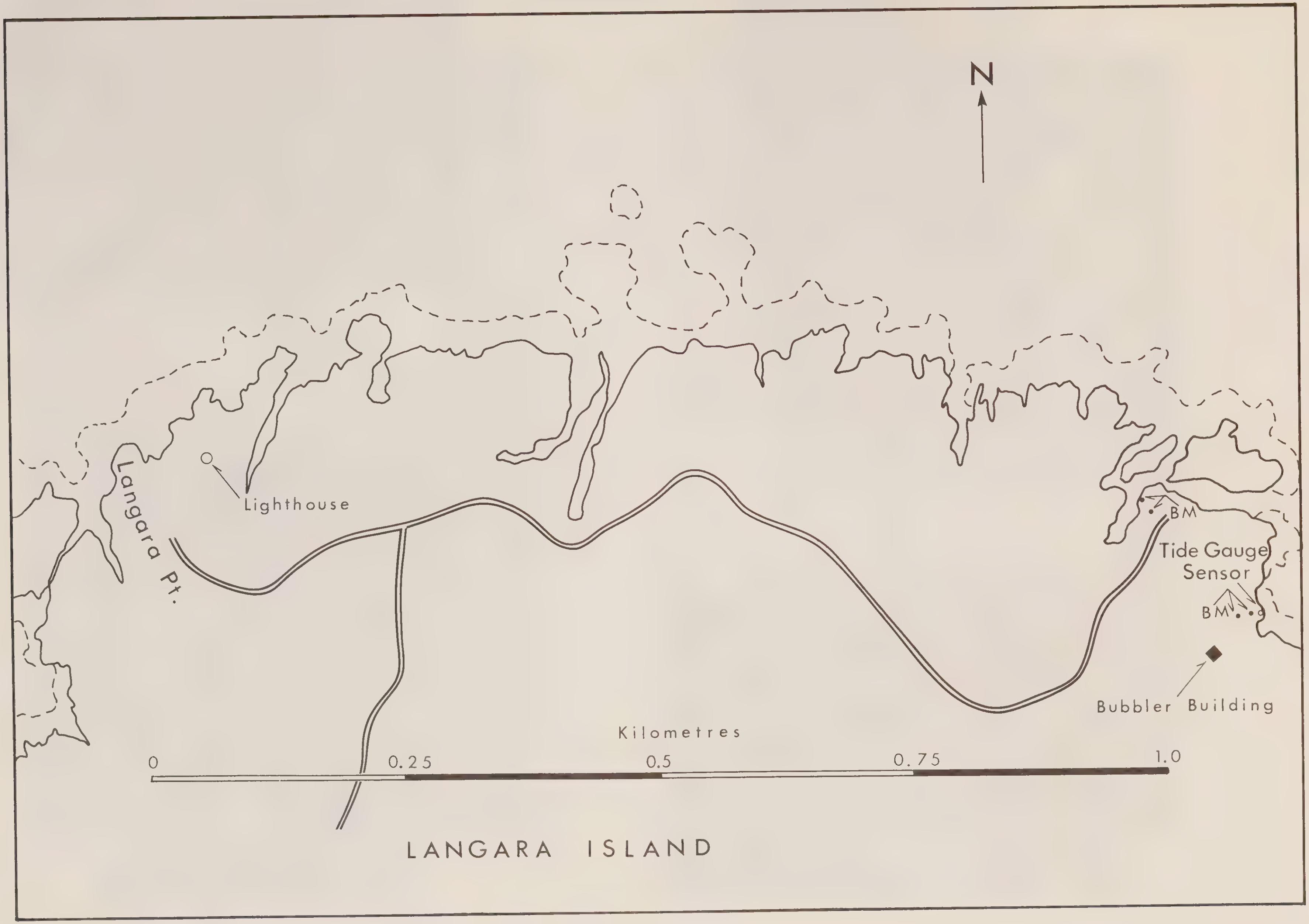
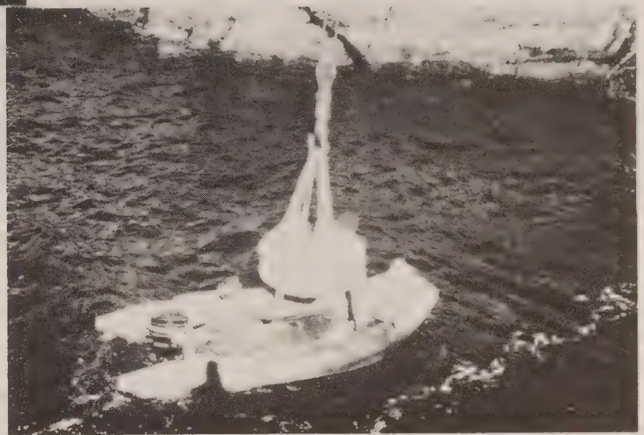


Figure 17

Langara Island Tide Gauge Site

New Bubbler Site– Bubbler Building
Figure 18



Loading Concrete Bags into Canova Boat
Figure 19

Loading Concrete Bags Into Canova Boat
Figure 20

Divers Placing Concrete Bags Over Submarine Cable
Figure 21

Original Langara Receiving Antenna on Mount Hays

Figure 22

Original Stencilled Tide Scales at Langara

Figure 23

Original Bubbler Building Site

Figure 24

Bubbler Building Site After Reinforced Concrete Buffer Wall Built

Figure 25

Walter Zubrycky Repairing the Tide Gauge Transmitting Antenna on the Light House
Figure 26

Jay Scott Drilling Holes to Secure the Tide Gauge Transmitting Antenna
Figure 27

Clearing Roadway Langara– Winter 1976
Figure 28

Caution Signs Along Roadway
Figure 29

Plastic Metric Tide Scale Attached to Concrete Culvert
Figure 30

Light House Wharf Loading Site After Storm

Figure 31

Light House Wharf Loading Site After Storm

Figure 32

Front of Bubbler Building After Storm

Figure 33

Water Surrounding Bubbler Building During High Water and Storms

Figure 34

Bubbler Building–Moving Day
Figure 35

The Workers – Moving Bubbler Building
Figure 36

The Workers – Raising Bubbler Building to New Foundation
Figure 37

The Workers – Bubbler Building at New Site
Figure 38

The Ditch – Diggers – Bubbler Building Drainage
Figure 39

Bubbler Building Drainage System
Figure 40

Bubbler Building at New Site – Old Site in Background

Figure 41

Bubbler Building New Site Viewed From Beach Old Site on Right

Figure 42

Plank Walkway to Bubbler Building

Figure 43

Langara – Ottboro Recorder
Figure 44

Langara – Hagenuk Recorder
Figure 45

New Langara Receiving Antenna On Mount Hays
Figure 46

Bubbler Building – Transducer, Ottboro and Manometer

Figure 47

Bubbler Building – Nitrogen Tanks, Regulators and Relief Valve.

Figure 48

Bubbler Building – Ottboro, Manometer, Bubbler and Nitrogen Systems.

Figure 49

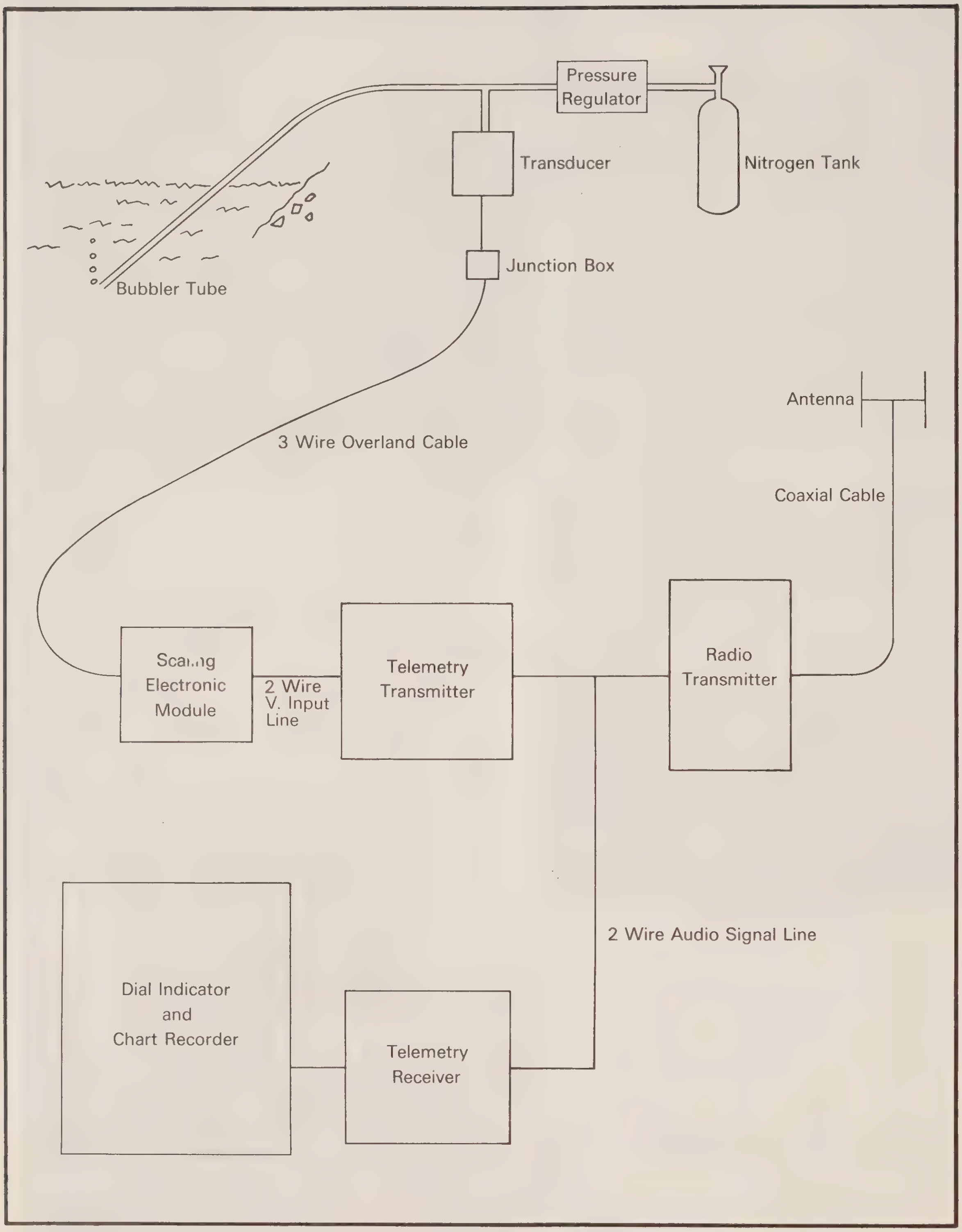


Figure 50

Block Diagram
Transmitting Site

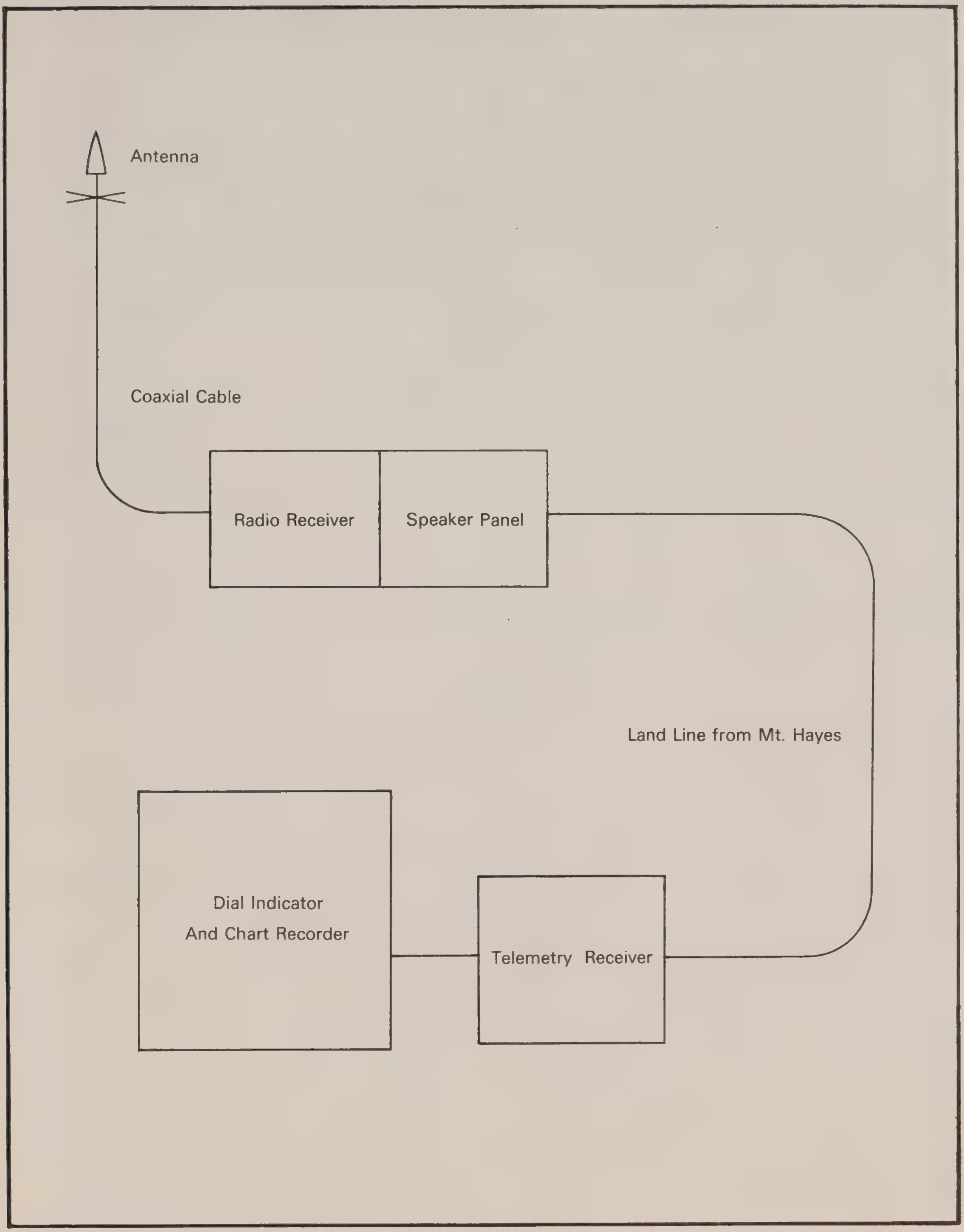


Figure 51

Block Diagram
Receiving Site

Langara Island. Wartime Carved Face Beside Old Plank Road to Radar
Figure 52

Pacific Marine Science Report 81-6

OBSERVATIONS OF SEAWATER TEMPERATURE AND SALINITY AT CAPE BEALE LIGHTSTATION AND BAMFIELD MARINE STATION 1969 - 1977

by

L.F. Giovando

INSTITUTE OF OCEAN SCIENCES
Sidney, B.C.

For additional copies or further information please write to:

Department of Fisheries and Oceans
Institute of Ocean Sciences
P.O. Box 6000
Sidney, B.C. CANADA
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OBSERVATIONS OF SEAWATER TEMPERATURE AND SALINITY AT CAPE BEALE LIGHTSTATION AND BAMFIELD MARINE STATION 1969-1977

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Sidney, B.C.

1981

Abstract

Surface (approximately one-metre-depth) oceanic salinities and temperatures have been recorded once daily at the Marine Biological Station at Bamfield, Vancouver Island, British Columbia since 12 July 1969, and at the federal Ministry of Transport (MOT) lightstation at Cape Beale (about 7 km southwest of Bamfield) since 9 January 1971.

At both locations, temperatures are obtained by a mercury-in-glass thermometer. Salinity values for each site are determined by means of a laboratory-model inductive (electrodeless) salinometer.

This report presents the surface-water data available, from each station, from the commencement of sampling through to the end of 1977. They are presented in two forms. Firstly, tabulations provide, for each site, the monthly means and the associated standard deviations, as well as the maximum and minimum values recorded during each month. The annual means, as well as the mean-monthly values for the several-year periods involved, are also given. Secondly, graphs indicate the behaviour, throughout each year, of the data after the higher frequency oscillations (e.g. those associated with lunar tides) have been removed ("smoothed") by the use of a seven-day normally-weighted running mean.

Introduction

Observations of (near) sea-surface salinity and/or temperature have been made once a day - weather and other conditions permitting - at numerous locations on the coast of British Columbia since the early 1930's. Most of these sampling sites have been at lightstations maintained by the federal Ministry of Transport (MOT) or its organizational predecessors. The number of sites reporting at any given time has varied throughout the years; sampling has been discontinued (and, in a few cases, later resumed) at some places and commenced (not necessarily simultaneously) at others. The sea-surface data obtained prior to 1978 at all but two of these locations have been disseminated in numerous publications (e.g. Hollister and Sandnes, 1972; Giovando, 1978). The two exceptions are the MOT lightstation at Cape Beale and the Marine Biological Station at Bamfield (hereafter termed "Bamfield"). Sampling at Cape Beale has been carried out under the direction of Bamfield. Both stations are located on the eastern side of the mouth of Barkley Sound, on the Pacific coast of Vancouver Island; they are about 7 km apart (Figure 1).

Surface temperature and salinity have been obtained once daily at Bamfield since 12 July 1969 and at Cape Beale since 9 January 1971. In late 1978, these hitherto-unreported data were made available for publication in this report series. The results for 1978 itself have been published together with those from the other shorestations reporting during that year (Giovando, 1980). The present publication lists all data available - from both locations - from the inception of sampling through to the end of 1977.

Observational Procedures and Equipment

Each daily sampling is scheduled for one hour before the daytime high tide. This objective occasionally may not be met, as the exact sampling time can depend upon both weather conditions and the press of the observer's other duties; however, only samples obtained within ± one hour of the desired time are recorded. Sampling is never attempted in darkness. The water is obtained by bucket at Cape Beale and by Van Dorn sampling bottle at Bamfield.

At both stations, the water temperature is measured by means of a mercury-in-glass thermometer, of range -10 to 60°C and of interval 0.5°C. The thermometers are accurate to within ± 0.2°C.

During the entire period covered by this report, the daily temperatures at Bamfield were estimated only to the nearest 0.5°C. The corresponding Fahrenheit values tabulated here (see next Section) will therefore be characterized by an uncertainty of almost 1 degree - which was, however, deemed tolerable during the period that these data were obtained. During 1978, however, temperatures at Bamfield have been reported to the nearest 0.1°C (as has been done at other stations utilizing the Celsius scale). It is hoped that this practice will continue. In contrast, all temperatures obtained at Cape Beale since the inception of sampling there have been estimated to ± 0.1°C.

At the same time that the sea temperature is taken, a glass bottle, of about 57-cc (2-oz) capacity, is filled with water from the bucket (or the Van Dorn bottle). This "sub-sample" is for use in the determination of salinity. The filled bottles are stored in wooden boxes containing 100 apiece; in the case of Cape Beale they are forwarded to Bamfield, where the salinities for both stations are determined. The analysis is carried out on a Kahlsico Model RSB-7 laboratory-type inductive (electrodeless) salinometer. The accuracy of this instrument is claimed by the manufacturer to be ± 0.003 parts per thousand (^{o}/oo). Salinities are estimated to the nearest 0.001 ^{o}/oo.

Processing of the Data

The data are scanned, and an individual value is rejected if it is obviously the result of a misreading or other procedural error, or if it is found, or suspected, that a faulty thermometer has been used. The temperatures have been converted from the original Celsius values to the corresponding ones in Fahrenheit. These conversions were carried out to provide compatibility with the corresponding information from other British Columbia shorestations - all of which obtained prior to 1978 has been published in ^{o}F. (All temperature data for 1978 (Giovando, 1980) and succeeding years are to be published in ^{o}C, in recognition of the present predominance of the Celsius scale in marine-related studies.)

If observations are missing for *one* day or for *two consecutive* days, the resulting gap is filled by value(s) obtained by linear interpolation utilizing the two observations bounding the gap. No interpolated values are provided when readings have been missed for *three or more* consecutive days.

The daily temperature and salinity data remaining after preliminary treatment are processed into final form by the Marine Environmental Data Services Branch (MEDS) of Ocean and Aquatic Sciences (OAS), DFE, in Ottawa (Somers, 1965). The computer processing involves the determination of the monthly means for temperature and for salinity, the corresponding standard deviations, and the annual means. Also, the mean-monthly values for the several-year periods treated in this report have been calculated for both sites. The means for temperature are rounded to the first decimal place, those for salinity to the second place. Standard deviations for temperature are rounded to the second decimal place, those for salinity to the third place. Data obtained by interpolation are not utilized in the computation of the means.

A form of smoothing is performed on the data to minimize the effect of any variability associated with frequencies large compared to the annual frequency (those associated with lunar tides, for example). For simplicity, the daily values of salinity and/or temperature at each sampling station are here considered to be equally spaced in time - with a sampling interval, therefore, of 24 hours. A seven-day, normally-weighted running mean (Holloway, 1958) is utilized to smooth the resulting series; this form of filtering is considered to result in an output free of such defects as

"polarity reversals" or phase shifts. The running mean is computed, for the entire year, for both temperature and salinity. (In order that these means for each station be as continuous as possible consistent with the data involved, interpolated daily values are utilized in the associated computations. However when a period of greater than *two* consecutive days of missed data is encountered the computations will be interrupted.)

Presentation of the Data

The data are presented on pages 11 to 113. For each station, the information is provided in two forms:

(1) Tabulations, in monthly format, of the daily values of temperature in °F and of salinity in parts per thousand (°/oo). The tables for Cape Beale are given on pages 12 to 39, those for Bamfield on pages 58 to 93. Three months' data are listed on each page. Also recorded for each month are the mean, the standard deviation (STD.DEV.), the number of observations (OBSVNS.) involved in the computations of these two quantities, and the MAXIMUM and MINIMUM values. The *annual* means (YRLY. MEANS) for temperature and salinity are included with the December output for each station. Each interpolated daily value is identified by an asterisk (*). "Missed" values with which no interpolation is associated are denoted by a "*0.0(0)" entry.†
Both the latitude and longitude of each station (in degrees, minutes and seconds) are noted on every page, immediately after the station designation.

For ease in reference, monthly- and annual means, as well as mean-monthly values, have been summarized for both temperature and salinity. Values in °F for Cape Beale and for Bamfield are given in Table 1; the equivalents in °C (to the nearest 0.1°) are provided in Table 2. Means for salinity are reported in Table 3.

(2) "Annual" graphs of the seven-day, normally-weighted running means for temperature and salinity. The graphs for Cape Beale are displayed on pages 42 to 55, those for Bamfield on pages 96 to 113. They are copies of the computer-generated plots of the means. Any interruption in the associated computations - due to missing data - will result in a gap in the plotted output as well. Each graph for temperature is provided with scales in both °C and °F.

Three characteristics of the data presented should be noted:

(a) Appreciable data gaps are seen to occur for both sites (not necessarily coincidentally). At present, no information upon temperature, or salinity, or both, is available for periods of up to several months. Extreme examples are (approximately): August through November, 1972, Cape Beale (temperature); July through November, 1973, Bamfield (salinity); February through September, 1974, Bamfield, and June through September, 1974, Cape Beale (temperature and salinity).

†Invalid days, such as April 31, are indicated by a "0.0 (0)" entry.

It should be remarked that data were indeed obtained during most of these periods. However, the information was misplaced at Bamfield, and an intensive search has so far failed to locate it. Should the data be found, they will be published as an appendix to the shorestation annual report in preparation at the time.

(b) Several months are characterized by having a number of daily values considerably less than the maximum possible. The reader is alerted to these cases, in Tables 1, 2 and 3, by means of the symbols "++" and "+". The symbol "++" identifies those monthly means to which only 1 to 10 daily values have contributed, while "+" indicates those for which 11 to 20 such values are available. (Each unmarked mean has therefore been calculated from more than 20 daily values.) Because of the small amount of data used to calculate them, those means characterized by "++" have, arbitrarily, not been utilized (as OBSVNS) in the calculation of either annual means or mean-monthly values (Tables 1, 2 or 3).

(c) Annual means for temperature or salinity have been omitted in the data tabulations, as well as in Tables 1, 2 and 3, if the number of monthly means assumed useful for their calculation is less than 10. This, again, is arbitrary. However, the possibility is strong that those annual values lacking several monthly means will be unrepresentative and misleading — especially in the case of temperature, which is generally featured by a pronounced annual cycle in British Columbia coastal surface waters.

Acknowledgements

Thanks are due to the technical staff at Bamfield and to A.D. Thomson and G. Jewsbury at Cape Beale for their efforts in obtaining the data. We are indebted to the former Director of the Marine Station at Bamfield, Dr. J.E. MacInerney, for his permission to publish these data, and to Miriam Preker and Sabina Leader for making them, as well as other relevant information, available. The computations were carried out by the Data Processing and Analysis Section of MEDS under the direction of Mr. J. Nasr.

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Figure 1. Location of Cape Beale and Bamfield (underlined).

Table 1. Monthly- and annual means, and mean-monthly values: Temperature (°F)

STATION Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
CAPE BEALE													
1971	45.9	45.3	44.7	48.0	50.2	53.5	54.8	55.2	53.9	50.5	48.6	45.4	49.7
1972	43.4	43.6	46.4	47.5	51.8	52.4	+55.2	-	-	-	-	45.7	-
1973	44.8	45.6	47.2	49.1	51.1	+50.9	54.4	55.4	54.9	51.9	48.5	-	50.3
1974	-	-	-	48.5	+49.1	-	-	-	-	+49.3	48.8	48.8	-
1975	45.8	++43.4	-	47.3	50.6	51.4	52.7	53.4	52.9	51.7	49.4	45.6	50.1
1976	45.0	44.1	44.9	47.5	49.8	52.3	53.7	52.7	52.5	49.8	-	47.5	49.1
1977	46.6	47.4	47.3	48.8	50.7	53.3	53.5	54.0	54.4	50.9	+48.5	46.9	50.2
Mean-monthly value	45.2	45.2	46.1	48.1	50.5	52.3	54.1	54.1	53.7	50.7	48.8	46.6	
Number of OBSVNS	6	5	5	7	7	6	6	5	5	6	5	6	
BAMFIELD													
1969	-	-	-	-	-	-	+62.1	+60.1	56.6	53.5	50.0	47.6	-
1970	45.2	46.8	47.6	49.5	53.4	60.2	60.5	61.1	55.4	51.7	48.8	44.3	52.0
1971	44.2	44.7	44.6	48.3	53.4	56.2	60.5	61.6	55.9	53.5	47.1	43.0	51.1
1972	42.0	42.8	44.3	45.4	55.1	60.3	61.1	58.3	56.0	50.9	48.3	45.3	50.8
1973	44.3	45.6	47.0	+51.4	53.4	56.8	61.7	-	-	54.5	-	++43.3	-
1974	+43.2	-	-	-	-	-	-	-	-	+46.9	+46.4	+43.2	-
1975	42.9	43.8	43.2	-	+53.0	+60.3	61.2	+60.5	-	-	-	++48.1	-
1976	++46.4	++45.2	-	-	+52.5	57.7	+59.7	++58.5	++59.0	-	-	-	-
1977	-	-	-	-	+55.1	+58.6	++58.5	++63.2	-	-	-	-	-
Mean-monthly value	43.6	44.7	45.3	48.6	53.7	58.6	61.0	60.3	56.6	51.8	48.1	44.7	
Number of OBSVNS	6	5	5	4	7	7	7	5	4	6	5	5	

++Means with 1 to 10 daily values of temperature recorded; these averages are <u>not</u> utilized in the calculations of either the annual means or the mean-monthly values.

+Months with 11 to 20 daily values of temperature recorded.

Table 2. Monthly- and annual means, and mean-monthly values: Temperature (°C)

STATION Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
CAPE BEALE													
1971	7.7	7.4	7.1	8.9	10.1	11.9	12.7	12.9	12.2	10.3	9.2	7.4	9.8
1972	6.3	6.4	8.0	8.6	11.0	11.3	+12.9	-	-	-	-	7.6	-
1973	7.1	7.6	8.4	9.5	10.6	+10.5	12.4	13.0	12.7	11.1	9.2	-	10.2
1974	-	-	-	9.2	+9.5	-	-	-	-	+9.6	9.3	9.3	-
1975	7.7	++6.3	-	8.5	10.3	10.8	11.5	11.9	11.6	10.9	9.7	7.6	9.7
1976	7.2	6.7	7.2	8.6	9.9	11.3	12.1	11.5	11.4	9.9	-	8.6	9.5
1977	8.1	8.6	8.5	9.3	10.4	11.8	11.9	12.2	12.4	10.5	+9.2	8.3	10.1
Mean-monthly value	7.3	7.3	7.8	8.9	10.3	11.3	12.3	12.3	12.1	10.4	9.3	8.1	
Number of OBSVNS	6	5	5	7	7	6	6	5	5	6	5	6	
BAMFIELD													
1969	-	-	-	-	-	-	+16.7	+15.6	13.7	11.9	10.0	8.7	-
1970	7.3	8.2	8.7	9.7	11.9	15.6	15.8	16.2	13.0	10.9	9.3	6.8	11.1
1971	6.8	7.1	7.0	9.1	11.9	13.4	15.8	16.4	13.3	11.9	8.4	6.1	10.6
1972	5.6	6.0	6.8	7.4	12.8	15.7	16.2	14.6	13.3	10.5	9.1	7.4	10.4
1973	6.8	7.6	8.3	+10.8	11.9	13.8	16.5	-	-	12.5	-	++6.3	-
1974	+6.2	-	-	-	-	-	-	-	-	+8.3	+8.0	+6.2	-
1975	6.1	6.6	6.2	-	+11.7	+15.7	16.2	+15.8	-	-	-	++8.9	-
1976	++8.0	++7.3	-	-	+11.4	14.3	+15.4	++14.7	++15.0	-	-	-	-
1977	-	-	-	-	+12.8	+14.8	++14.7	++17.3	-	-	-	-	-
Mean-monthly value	6.5	7.1	7.4	9.2	12.1	14.8	16.1	15.7	13.7	11.0	9.0	7.0	
Number of OBSVNS	6	5	5	4	7	7	7	5	4	6	5	5	

++Months with 1 to 10 daily values of temperature recorded; these averages are <u>not</u> utilized in the calculations of either the annual means or the mean-monthly values.

+Months with 11 to 20 daily values of temperature recorded.

Table 3. Monthly- and annual means, and mean-monthly values: Salinity ($^{o}/oo$)

STATION Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
CAPE BEALE													
1971	29.60	28.88	29.58	29.60	30.70	29.72	30.24	30.75	30.82	30.69	30.11	30.12	30.08
1972	30.53	28.90	27.25	28.73	30.16	30.76	29.65	30.74	31.25	31.70	31.01	30.49	31.10
1973	29.79	30.43	30.25	31.51	31.48	+31.66	31.62	31.72	31.73	31.39	30.47	-	31.09
1974	-	-	-	29.43	+30.17	-	-	-	-	+31.56	30.41	30.27	-
1975	30.28	29.73	-	31.29	30.93	30.97	31.30	31.32	++31.74	30.02	29.11	+29.84	30.48
1976	29.42	30.55	+30.94	29.52	30.50	29.57	30.25	30.48	+30.43	30.75	30.87	30.79	30.34
1977	30.61	30.60	30.74	31.44	31.08	30.97	31.70	+31.88	31.46	31.36	+30.40	28.88	30.93
Mean-monthly value	30.04	29.85	29.75	30.22	30.72	30.61	30.79	31.15	31.12	31.07	30.34	30.06	
Number of OBSVNS	6	6	5	7	7	6	6	6	5	7	7	6	
BAMFIELD													
1969	-	-	-	-	-	-	+27.89	28.98	27.76	28.16	26.81	29.14	-
1970	29.11	27.00	27.39	26.71	29.15	29.12	30.20	29.76	30.09	30.14	28.88	28.04	28.80
1971	26.43	24.30	26.04	26.56	24.59	23.63	23.46	26.92	29.00	28.33	26.74	28.72	26.23
1972	28.36	+27.90	-	-	25.06	24.28	++28.03	-	29.77	++29.72	-	25.33	-
1973	26.71	29.50	25.93	+28.43	27.43	+26.01	-	-	-	-	-	++29.11	-
1974	+29.03	-	-	-	-	-	-	-	-	-	-	-	-
1975	-	-	-	-	+29.40	+27.38	30.42	+31.97	-	-	-	++26.77	-
1976	++29.11	++29.33	-	-	+28.93	+25.75	+25.75	++26.65	++26.70	++27.98	30.93	++31.19	-
1977	-	-	-	-	+27.87	+26.80	++29.26	++29.74	-	-	-	-	-
Mean-monthly value	27.93	27.17	26.45	27.23	27.49	26.14	27.54	29.41	29.15	28.88	28.34	27.81	
Number of OBSVNS	5	4	3	3	7	7	5	4	4	3	4	4	

++Months with 1 to 10 daily values of salinity recorded; these averages are not utilized in the calculations of either the annual means or the mean-monthly values.

+Months with 11 to 20 daily values of salinity recorded.

Tabulations of Daily Sea-surface

Temperature and Salinity

1971-1977

CAPE BEALE

TEMP: Temperature (^{o}F)

SAL: Salinity (^{o}/oo)

CAPE BEALE 48 47 12 N 125 12 53 W

DATE	JANUARY TEMP	JANUARY SAL	FEBRUARY TEMP	FEBRUARY SAL	MARCH TEMP	MARCH SAL 1971
1	* 0.0	* 0.00	45.7	25.56	44.4	30.40
2	* 0.0	* 0.00	43.7	27.24	44.4	29.66
3	* 0.0	* 0.00	44.4	27.35	44.2	30.57
4	* 0.0	* 0.00	44.6	30.43	44.2	30.50
5	* 0.0	* 0.00	* 44.1	* 30.42	43.9	30.48
6	* 0.0	* 0.00	43.7	30.40	43.2	30.06
7	* 0.0	* 0.00	43.3	30.26	43.7	28.45
8	* 0.0	* 0.00	44.4	30.47	42.8	30.02
9	46.4	29.73	44.8	30.32	42.6	25.82
10	46.4	31.31	46.0	28.81	44.2	30.21
11	46.4	31.63	46.0	30.16	44.2	30.27
12	46.4	31.46	46.0	29.35	44.6	29.54
13	44.6	31.23	46.4	28.88	44.6	29.32
14	44.6	30.48	46.6	24.56	44.6	28.72
15	44.6	30.34	46.4	28.04	44.6	30.71
16	44.6	30.35	46.4	29.17	44.6	29.71
17	46.2	29.43	45.7	27.40	45.0	29.91
18	46.4	26.44	46.0	28.07	46.4	30.20
19	46.0	26.81	46.0	27.99	46.2	29.83
20	44.2	29.03	46.0	27.99	46.2	29.49
21	44.6	30.69	46.0	31.06	44.6	29.52
22	46.2	30.46	45.7	* 29.56	44.6	29.57
23	46.2	30.19	45.3	28.07	45.5	26.20
24	46.4	30.34	45.0	27.99	44.6	29.06
25	45.5	31.66	44.6	29.99	45.0	30.44
26	46.2	26.52	44.6	31.06	45.0	30.14
27	46.4	29.55	44.4	29.74	44.4	29.66
28	46.4	* 28.37	44.4	30.44	45.0	28.95
29	46.2	27.19	0.0	0.00	45.5	29.23
30	46.4	26.75	0.0	0.00	46.4	30.02
31	47.3	* 26.15	0.0	0.00	46.4	30.34
MEANS	45.9	29.60	45.3	28.88	44.7	29.58
OBSVNS.	23	21	27	26	31	31
MAXIMUM	47.3	31.66	46.6	31.06	46.4	30.71
MINIMUM	44.2	26.44	43.3	24.56	42.6	25.82
STD.DEV.	.86	1.784	.95	1.654	.97	1.107

CAPE BEALF 48 47 12 N 125 12 53 W

	APRIL		MAY		JUNE	1971
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	46.4	30.06	50.0	30.71	50.0	31.01
2	47.8	29.09	52.0	29.27	50.9	31.52
3	48.2	29.78	52.3	27.74	50.0	31.84
4	46.4	29.91	50.5	29.22	50.0	31.87
5	47.5	29.59	48.2	30.69	52.2	30.27
6	48.2	28.55	48.2	31.31	* 51.6	* 30.81
7	47.3	29.54	51.3	30.17	51.1	31.36
8	46.4	31.20	51.8	30.95	51.8	31.04
9	46.8	28.57	50.0	31.12	52.3	29.35
10	46.4	29.03	52.7	30.77	52.7	30.21
11	47.3	28.83	53.2	30.51	51.6	30.66
12	48.2	28.12	51.3	31.05	51.8	30.22
13	49.6	29.12	* 49.7	* 30.87	51.4	30.61
14	49.3	27.44	48.2	30.70	52.2	30.82
15	48.2	29.25	48.2	30.60	53.6	29.69
16	47.8	29.55	49.3	30.46	53.6	29.09
17	48.2	29.78	53.6	30.91	59.0	28.63
18	48.2	29.91	49.6	30.96	55.8	29.38
19	48.2	* 29.78	48.0	30.43	55.4	29.50
20	47.5	29.65	48.9	31.37	54.0	29.22
21	47.3	29.85	50.0	31.49	54.7	29.82
22	46.8	29.78	50.0	30.77	53.2	30.31
23	46.9	29.99	50.0	31.30	56.5	* 28.77
24	48.6	30.19	50.0	31.65	53.6	27.23
25	50.2	29.82	51.8	29.78	55.0	28.70
26	50.9	30.50	51.8	29.25	55.4	29.22
27	48.2	30.53	49.6	31.57	56.1	26.83
28	49.1	30.18	49.1	31.54	55.9	28.02
29	48.7	30.47	49.6	31.33	56.3	27.66
30	50.0	30.10	48.7	31.74	55.4	28.03
31	0.0	0.00	49.5	31.56	0.0	0.00
MEANS	48.0	29.60	50.2	30.70	53.5	29.72
OBSVNS.	30	29	30	30	29	28
MAXIMUM	50.9	31.20	53.6	31.74	59.0	31.87
MINIMUM	46.4	27.44	48.0	27.74	50.0	26.83
STD.DEV.	1.18	.785	1.59	.896	2.30	1.367

CAPE BEALE 48 47 12 N 125 12 53 W

	JULY		AUGUST		SEPTEMBER 1971	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	55.4	26.75	58.1	30.05	53.1	31.28
2	55.4	28.36	59.0	28.79	53.1	31.17
3	53.2	30.23	55.8	30.15	53.2	31.28
4	54.0	28.13	55.4	30.42	53.6	29.70
5	52.5	29.23	55.0	30.47	55.4	30.47
6	53.2	29.72	* 55.2	* 30.33	53.8	30.91
7	* 52.9	* 30.14	55.4	30.19	54.0	30.86
8	* 52.5	* 30.56	54.7	30.65	54.3	30.93
9	52.2	30.98	57.0	30.01	55.9	30.78
10	52.9	30.63	57.2	29.96	55.4	29.87
11	53.6	30.69	53.6	30.86	57.2	30.38
12	* 53.2	* 30.75	51.8	31.38	55.6	30.94
13	52.9	30.82	54.9	31.08	53.8	30.76
14	57.2	28.83	55.4	31.30	53.4	30.78
15	54.5	30.07	59.2	29.14	53.6	30.38
16	54.0	31.03	57.4	30.26	54.0	30.05
17	55.8	30.37	53.8	30.30	54.3	30.70
18	55.4	30.61	53.6	31.71	53.6	31.13
19	55.8	30.91	53.6	31.30	53.6	30.96
20	57.6	31.05	53.6	31.25	54.5	30.53
21	55.0	31.36	53.1	31.20	53.6	31.21
22	52.2	31.55	* 53.4	* 31.17	53.6	31.20
23	52.3	31.54	53.8	31.14	53.6	30.90
24	53.4	31.01	53.2	31.04	52.7	31.22
25	56.1	30.19	54.9	31.00	52.7	31.18
26	56.1	30.89	53.8	31.96	53.6	31.17
27	54.7	31.27	57.4	30.48	53.6	31.01
28	54.5	31.06	* 56.4	* 31.12	51.8	30.95
29	58.6	30.71	55.4	31.75	* 51.7	* 31.00
30	57.2	30.12	54.7	31.71	51.6	31.04
31	59.2	28.61	53.8	31.51	0.0	0.00
MEANS	54.8	30.24	55.2	30.75	53.9	30.82
OBSVNS.	28	28	28	28	29	29
MAXIMUM	59.2	31.55	59.2	31.96	57.2	31.28
MINIMUM	52.2	26.75	51.8	28.79	51.6	29.70
STD.DEV.	1.94	1.169	1.88	.776	1.17	.417

CAPE BEALF 48 47 12 N 125 12 53 W

DATE	OCTOBER TEMP	OCTOBER SAL	NOVEMBER TEMP	NOVEMBER SAL	DECEMBER 1971 TEMP	DECEMBER 1971 SAL
1	51.8	31.04	49.3	30.90	48.2	29.82
2	51.8	30.94	48.9	31.16	48.2	30.27
3	* 52.1	* 30.23	49.8	28.66	48.2	30.43
4	52.3	29.52	48.4	31.28	48.0	30.13
5	51.8	30.55	47.8	31.21	48.2	30.55
6	53.4	29.96	48.0	31.10	48.2	30.91
7	50.9	* 30.37	48.2	30.82	46.8	30.81
8	52.9	30.78	48.2	29.43	44.8	26.16
9	52.7	30.79	48.6	29.81	46.9	30.76
10	53.1	30.86	48.2	30.16	46.8	31.61
11	53.2	31.11	48.2	29.78	46.8	31.10
12	52.0	30.72	48.2	30.06	46.8	30.70
13	52.3	30.29	48.9	29.87	45.0	30.38
14	49.8	30.47	49.6	29.48	44.6	30.16
15	49.1	31.70	49.1	29.98	43.7	31.12
16	48.4	31.75	48.9	29.86	45.5	29.80
17	49.8	31.29	48.2	30.43	45.5	30.45
18	48.9	31.62	48.4	30.40	45.5	31.13
19	* 48.8	* 31.33	49.3	29.46	45.5	31.07
20	48.7	31.03	50.0	29.14	45.5	31.03
21	48.0	31.16	48.9	30.04	45.5	31.12
22	48.9	30.54	48.2	30.46	43.7	30.59
23	50.7	31.21	48.2	29.90	43.7	30.34
24	50.2	31.29	48.2	30.21	43.7	.64
25	51.8	27.59	* 48.2	* 29.26	43.7	30.51
26	50.0	31.22	48.2	28.32	42.8	30.10
27	48.2	31.29	48.2	30.51	43.7	29.13
28	48.2	29.29	48.2	30.46	42.8	27.91
29	48.2	29.71	48.6	30.26	42.8	27.80
30	48.2	30.49	48.6	30.13	42.8	28.65
31	48.9	31.06	0.0	0.00	44.6	29.17
MEANS	50.5	30.69	48.6	30.11	45.4	30.12
OBSVNS.	29	28	29	29	31	30
YRLY.MEANS..					49.7	30.08
MAXIMUM	53.4	31.75	50.0	31.28	48.2	31.61
MINIMUM	48.0	27.59	47.8	28.32	42.8	26.16
STD.DEV.	1.84	.866	.57	.715	1.85	1.187

CAPE BEALF 48 47 12 N 125 12 53 W

	JANUARY		FEBRUARY		MARCH	1972
DATF	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	45.5	29.98	42.6	30.63	43.7	29.10
2	44.2	30.57	41.5	30.46	44.6	29.29
3	44.6	30.92	41.0	29.86	44.6	28.84
4	44.6	30.67	41.5	29.69	44.6	28.94
5	44.8	30.44	42.1	29.68	44.6	26.46
6	44.6	30.68	42.8	28.36	44.6	27.82
7	43.7	30.19	43.5	28.37	* 44.8	* 28.13
8	44.6	30.29	42.8	29.32	45.0	28.44
9	44.6	31.39	42.3	29.45	45.3	27.24
10	42.8	31.16	42.8	29.55	46.4	26.15
11	43.7	30.43	42.8	29.80	46.4	25.98
12	42.8	30.66	43.5	29.03	47.8	24.92
13	42.8	31.58	44.1	30.34	47.8	24.78
14	43.0	31.32	42.8	30.08	47.5	26.07
15	44.6	30.93	44.6	30.12	48.2	24.66
16	44.6	29.83	44.4	30.33	* 48.3	* 26.89
17	43.0	31.33	44.6	30.90	48.4	29.13
18	43.3	31.37	45.1	29.02	* 48.3	* 27.81
19	44.6	29.64	44.8	27.50	48.2	26.49
20	44.8	28.09	44.6	28.59	47.3	27.12
21	45.0	30.50	43.2	26.21	* 47.4	* 25.94
22	44.6	30.95	44.2	27.33	47.5	24.75
23	41.9	29.81	44.4	26.96	45.3	26.70
24	41.4	31.32	44.4	28.15	46.4	27.28
25	41.0	31.11	43.3	26.90	44.8	27.58
26	41.7	30.70	43.9	27.74	45.7	27.87
27	41.0	30.17	45.9	27.09	48.2	27.22
28	41.0	29.87	46.0	28.19	48.2	28.03
29	41.5	29.72	44.6	28.44	48.4	27.93
30	42.6	30.13	0.0	0.00	48.2	28.48
31	42.6	30.64	0.0	0.00	46.4	28.60
MEANS	43.4	30.53	43.6	28.90	46.4	27.25
OBSVNS.	31	31	29	29	27	27
MAXIMUM	45.5	31.58	46.0	30.90	48.4	29.29
MINIMUM	41.0	28.09	41.0	26.21	43.7	24.66
STD.DEV.	1.38	.716	1.27	1.286	1.55	1.433

CAPE BEALE 48 47 12 N 125 12 53 W

	APRIL		MAY		JUNE	1972
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	46.6	29.81	47.8	29.96	53.6	30.42
2	47.3	30.14	* 49.1	* 29.37	53.6	30.52
3	47.8	30.15	50.4	28.78	53.6	30.17
4	48.2	29.96	52.7	28.21	51.8	31.19
5	48.0	28.14	51.8	29.89	52.5	31.06
6	46.4	28.24	51.4	29.07	53.2	30.51
7	46.4	28.68	52.0	29.80	* 51.7	* 31.08
8	46.2	27.79	50.7	29.50	50.2	31.65
9	46.4	27.28	50.9	28.47	50.7	31.41
10	47.7	27.24	51.4	28.96	50.7	30.05
11	46.9	26.14	50.7	29.37	51.1	31.44
12	48.0	26.44	51.8	29.87	51.8	31.27
13	48.2	27.01	52.0	29.57	53.6	30.94
14	48.2	25.58	52.7	29.26	51.8	30.02
15	47.1	28.69	50.0	30.46	51.4	30.04
16	47.3	28.34	51.8	29.21	* 51.8	* 30.60
17	48.2	28.41	49.8	29.92	52.3	31.15
18	48.4	29.63	* 52.3	* 30.48	55.0	28.77
19	48.2	27.69	54.9	31.04	54.0	29.97
20	48.2	29.85	52.2	31.40	53.4	31.22
21	46.2	29.79	51.3	31.32	51.8	31.53
22	46.0	30.09	51.4	31.34	51.8	30.98
23	47.1	29.67	50.0	31.41	51.8	31.61
24	48.0	29.39	51.3	31.26	52.3	31.54
25	48.0	30.24	52.3	30.92	51.8	31.33
26	47.7	29.57	52.5	31.18	51.8	31.46
27	* 47.7	* 29.43	54.7	31.41	52.7	30.31
28	47.8	29.29	53.2	30.84	52.2	30.36
29	48.2	30.26	54.7	30.92	53.2	29.93
30	47.8	29.61	53.2	30.70	52.3	30.55
31	0.0	0.00	52.0	30.73	0.0	0.00
MEANS	47.5	28.73	51.8	30.16	52.4	30.76
OBSVNS.	29	29	29	29	28	28
MAXIMUM	48.4	30.26	54.9	31.41	55.0	31.65
MINIMUM	46.0	25.58	47.8	28.21	50.2	28.77
STD.DEV.	.76	1.355	1.53	.990	1.12	.700

CAPE BEALE 48 47 12 N 125 12 53 W

DATE	JULY TEMP	JULY SAL	AUGUST TEMP	AUGUST SAL	SEPTEMBER 1972 TEMP	SEPTEMBER 1972 SAL
1	53.6	30.51	* 0.0	30.67	* 0.0	31.40
2	56.5	30.55	* 0.0	30.27	* 0.0	31.63
3	55.9	30.72	* 0.0	28.92	* 0.0	31.47
4	* 56.1	* 29.76	* 0.0	28.75	* 0.0	31.37
5	56.3	28.80	* 0.0	30.42	* 0.0	* 31.43
6	54.5	30.14	* 0.0	31.29	* 0.0	31.50
7	55.4	29.94	* 0.0	30.75	* 0.0	31.13
8	52.5	30.82	* 0.0	31.17	* 0.0	30.96
9	55.8	30.51	* 0.0	31.13	* 0.0	31.05
10	52.3	30.60	* 0.0	30.92	* 0.0	31.19
11	51.8	29.69	* 0.0	31.00	* 0.0	* 31.25
12	52.0	26.75	* 0.0	31.29	* 0.0	31.31
13	51.8	29.47	* 0.0	31.40	* 0.0	31.39
14	52.0	29.84	* 0.0	30.87	* 0.0	31.41
15	56.8	29.67	* 0.0	31.31	* 0.0	31.46
16	57.4	29.72	* 0.0	31.15	* 0.0	31.18
17	61.2	25.92	* 0.0	31.29	* 0.0	31.28
18	58.3	29.87	* 0.0	30.94	* 0.0	31.65
19	59.0	28.70	* 0.0	30.77	* 0.0	31.72
20	* 0.0	26.71	* 0.0	30.67	* 0.0	31.19
21	* 0.0	29.75	* 0.0	30.44	* 0.0	29.79
22	* 0.0	30.48	* 0.0	* 30.28	* 0.0	30.52
23	* 0.0	29.99	* 0.0	30.11	* 0.0	30.94
24	* 0.0	29.59	* 0.0	30.70	* 0.0	31.21
25	* 0.0	29.80	* 0.0	30.78	* 0.0	* 31.30
26	* 0.0	30.27	* 0.0	30.75	* 0.0	31.39
27	* 0.0	30.29	* 0.0	30.86	* 0.0	31.32
28	* 0.0	29.77	* 0.0	* 31.03	* 0.0	31.57
29	* 0.0	29.58	* 0.0	31.20	* 0.0	* 31.54
30	* 0.0	30.36	* 0.0	30.91	* 0.0	31.51
31	* 0.0	30.77	* 0.0	30.84	0.0	0.00
MEANS	55.2	29.65	0.0	30.74	0.0	31.25
OBSVNS.	18	30	0	29	0	26
MAXIMUM	61.2	30.82	0.0	31.40	0.0	31.72
MINIMUM	51.8	25.92	0.0	28.75	0.0	29.79
STD.DEV.	2.80	1.206	0.00	.618	0.00	.394

CAPE BEALE 48 47 12 N 125 12 53 W

	OCTOBER		NOVEMBER		DECEMBER 1972	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 31.51	* 0.0	31.75	* 0.0	31.20
2	* 0.0	31.51	* 0.0	* 31.25	* 0.0	31.36
3	* 0.0	31.55	* 0.0	30.75	* 0.0	31.57
4	* 0.0	31.72	* 0.0	31.07	* 0.0	31.64
5	* 0.0	31.89	* 0.0	31.57	45.5	31.47
6	* 0.0	31.89	* 0.0	30.03	44.4	31.48
7	* 0.0	31.93	* 0.0	* 30.71	44.4	31.49
8	* 0.0	31.88	* 0.0	31.39	45.0	31.54
9	* 0.0	31.40	* 0.0	29.98	44.6	31.56
10	* 0.0	31.99	* 0.0	30.85	44.6	31.92
11	* 0.0	32.06	* 0.0	31.13	44.8	31.47
12	* 0.0	31.72	* 0.0	31.31	45.0	31.65
13	* 0.0	31.88	* 0.0	31.26	44.2	31.53
14	* 0.0	31.72	* 0.0	31.15	43.3	31.66
15	* 0.0	31.80	* 0.0	30.64	45.1	31.62
16	* 0.0	31.74	* 0.0	30.98	45.9	30.78
17	* 0.0	31.81	* 0.0	30.92	46.4	30.20
18	* 0.0	31.70	* 0.0	30.94	45.7	29.22
19	* 0.0	31.60	* 0.0	30.98	46.2	30.81
20	* 0.0	31.52	* 0.0	30.09	46.6	29.47
21	* 0.0	31.33	* 0.0	31.00	46.6	28.87
22	* 0.0	31.29	* 0.0	31.24	46.6	30.13
23	* 0.0	31.28	* 0.0	30.32	46.6	28.80
24	* 0.0	31.50	* 0.0	30.93	46.4	29.15
25	* 0.0	31.66	* 0.0	31.38	47.3	28.58
26	* 0.0	31.80	* 0.0	31.38	47.7	30.34
27	* 0.0	31.69	* 0.0	31.19	46.8	29.32
28	* 0.0	* 0.00	* 0.0	31.20	46.2	29.52
29	* 0.0	* 0.00	* 0.0	31.47	46.2	28.79
30	* 0.0	* 0.00	* 0.0	31.26	46.2	28.72
31	* 0.0	32.10	0.0	0.00	46.0	29.43
MEANS	0.0	31.70	0.0	31.01	45.7	30.49
OBSVNS.	0	27	0	28	27	31
YRLY.MEANS..						30.10
MAXIMUM	0.0	32.10	0.0	31.75	47.7	31.92
MINIMUM	0.0	31.28	0.0	29.98	43.3	28.58
STD.DEV.	0.00	.225	0.00	.450	1.06	1.161

CAPE BEALE 48 47 12 N 125 12 53 W

	JANUARY		FEBRUARY		MARCH	1973
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	46.0	28.97	44.6	29.76	* 46.8	* 30.20
2	46.2	29.85	45.1	27.85	46.9	30.14
3	44.1	29.63	45.0	29.88	46.6	29.55
4	44.4	29.68	45.3	29.94	47.5	29.12
5	43.9	30.12	45.0	29.91	47.1	29.20
6	43.7	30.48	44.6	30.56	48.2	29.48
7	44.1	30.51	44.6	30.73	48.4	29.40
8	42.4	30.51	44.6	30.64	48.2	29.61
9	41.2	30.76	44.6	30.67	48.2	29.97
10	41.9	30.51	44.6	30.53	* 48.2	* 30.09
11	43.7	29.73	44.6	30.49	48.2	30.21
12	44.6	29.69	44.4	30.56	46.9	29.84
13	44.4	29.13	44.6	30.91	46.4	30.64
14	* 46.2	* 29.21	44.8	30.89	46.8	30.88
15	48.0	29.30	* 45.3	* 30.78	46.6	30.91
16	46.4	29.39	* 45.7	* 30.67	46.0	30.49
17	46.2	30.55	46.2	30.56	45.5	30.86
18	46.0	29.80	46.4	31.15	45.0	29.97
19	45.3	29.52	46.4	31.08	45.3	29.90
20	46.2	29.40	* 46.6	* 31.07	* 45.9	* 29.86
21	46.0	30.01	46.8	31.06	46.6	* 29.82
22	45.9	29.82	46.4	30.99	47.8	29.78
23	46.4	28.81	47.5	30.88	49.1	30.30
24	46.4	29.31	* 47.8	* 30.58	* 48.8	* 30.38
25	44.6	29.85	48.2	30.27	48.6	30.47
26	43.2	29.97	47.8	30.23	48.2	30.90
27	43.0	29.64	46.6	30.31	48.2	30.97
28	44.6	30.12	* 46.7	* 30.25	46.8	31.07
29	44.6	29.57	0.0	0.00	47.7	31.07
30	44.6	29.05	0.0	0.00	46.6	30.82
31	45.3	30.13	0.0	0.00	47.3	30.88
MEANS	44.8	29.79	45.6	30.43	47.2	30.25
OBSVNS.	30	30	23	23	27	26
MAXIMUM	48.0	30.76	48.2	31.15	49.1	31.07
MINIMUM	41.2	28.81	44.4	27.85	45.0	29.12
STD.DEV.	1.53	.511	1.19	.692	1.06	.624

CAPE BEALE 48 47 12 N 125 12 53 W

DATE	APRIL TEMP	APRIL SAL	MAY TEMP	MAY SAL	JUNE TEMP	JUNE SAL 1973
1	48.2	31.11	50.0	32.08	50.4	32.39
2	48.6	31.17	49.5	32.07	50.7	32.17
3	48.0	31.48	50.0	32.04	50.0	32.11
4	48.2	31.39	52.2	31.92	51.4	31.16
5	* 49.1	* 31.49	50.0	32.07	50.2	32.29
6	50.0	31.58	50.0	31.96	50.4	30.78
7	50.2	31.29	48.9	31.07	50.0	32.01
8	49.6	31.28	48.7	29.96	50.9	31.94
9	50.7	31.32	50.2	31.58	49.8	31.92
10	50.0	30.87	49.6	32.02	51.4	31.78
11	49.1	31.09	50.7	32.06	52.0	30.43
12	48.6	31.35	50.2	31.85	51.8	30.89
13	48.2	31.19	52.0	32.03	* 0.0	* 0.00
14	48.7	31.35	53.8	31.65	* 0.0	* 0.00
15	48.4	31.35	52.7	31.94	* 0.0	* 0.00
16	* 48.6	* 31.45	53.6	31.76	* 0.0	* 0.00
17	48.9	31.55	53.4	31.42	* 0.0	* 0.00
18	47.5	31.60	53.6	31.02	* 0.0	* 0.00
19	48.6	31.71	52.9	31.06	* 0.0	* 0.00
20	48.9	31.70	51.1	32.05	* 0.0	* 0.00
21	49.1	31.33	50.0	32.24	* 0.0	* 0.00
22	49.6	31.42	51.6	32.19	* 0.0	* 0.00
23	50.0	31.84	50.2	27.69	* 0.0	* 0.00
24	50.4	32.13	50.0	31.54	* 0.0	* 0.00
25	52.0	31.80	50.0	31.58	* 0.0	* 0.00
26	49.6	31.75	51.8	30.34	* 0.0	* 0.00
27	48.2	31.58	* 51.2	* 30.57	* 0.0	* 0.00
28	47.3	32.12	50.5	30.80	* 0.0	* 0.00
29	48.7	31.97	52.2	31.45	* 0.0	* 0.00
30	48.9	31.86	52.0	30.91	52.3	* 0.00
31	0.0	0.00	51.1	32.16	0.0	0.00
MEANS	49.1	31.51	51.1	31.48	50.9	31.66
OBSVNS.	28	28	30	30	13	12
MAXIMUM	52.0	32.13	53.8	32.24	52.3	32.39
MINIMUM	47.3	30.87	48.7	27.69	49.8	30.43
STD.DEV.	1.04	.314	1.47	.917	.83	.661

CAPE BEALE 48 47 12 N 125 12 53 W

	JULY		AUGUST		SEPTEMBER 1973	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	53.2	31.42	55.6	31.78	54.0	31.95
2	52.7	31.78	53.8	31.72	53.2	32.05
3	51.4	31.91	* 53.7	* 31.91	54.5	31.60
4	52.2	31.57	53.6	32.10	54.1	31.99
5	51.8	* 31.80	55.4	32.16	53.6	32.23
6	51.8	32.03	53.2	32.27	56.5	32.11
7	52.3	31.91	53.6	32.26	53.2	31.80
8	51.8	31.52	* 54.7	* 32.10	53.2	32.19
9	52.3	31.74	55.8	31.94	54.1	32.05
10	54.0	30.66	53.2	32.35	54.5	31.67
11	55.4	31.71	* 54.8	* 31.98	54.9	31.78
12	54.5	31.67	56.3	31.61	* 54.9	* 31.76
13	53.4	31.90	55.4	31.81	54.9	31.73
14	53.6	32.05	* 55.2	* 31.77	55.0	31.74
15	54.5	32.00	55.0	31.72	55.0	31.69
16	54.7	31.97	55.4	31.60	55.2	31.62
17	55.0	31.87	54.1	31.87	55.2	31.86
18	55.8	31.88	* 55.6	* 31.76	55.0	31.66
19	* 55.8	* 31.72	57.0	31.65	54.3	31.42
20	55.8	31.55	56.3	31.79	55.0	30.38
21	54.1	31.84	57.2	31.53	54.0	31.28
22	54.9	31.81	58.1	31.44	53.6	31.84
23	57.2	31.63	59.0	30.65	53.8	31.98
24	56.3	31.39	59.0	30.41	57.4	31.68
25	56.3	31.10	55.0	31.70	55.9	32.16
26	59.0	30.75	56.7	31.48	56.5	32.05
27	59.2	31.05	54.5	31.77	57.9	30.78
28	* 57.4	* 31.25	* 54.4	* 31.74	57.2	31.25
29	55.6	31.45	54.3	31.71	55.8	31.61
30	55.4	31.50	54.1	31.84	53.6	32.01
31	54.5	31.79	54.3	31.78	0.0	0.00
MEANS	54.4	31.62	55.4	31.72	54.9	31.73
OBSVNS.	29	28	25	25	29	29
MAXIMUM	59.2	32.05	59.0	32.35	57.9	32.23
MINIMUM	51.4	30.66	53.2	30.41	53.2	30.38
STD.DEV.	2.04	.365	1.68	.433	1.28	.410

CAPE BEALE 48 47 12 N 125 12 53 W

	OCTOBER		NOVEMBER		DECEMBER	1973
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	53.6	32.02	50.0	30.74	* 0.0	* 0.00
2	53.6	31.90	49.3	30.86	* 0.0	* 0.00
3	53.4	31.76	46.9	30.90	* 0.0	* 0.00
4	* 53.2	* 31.85	48.0	29.92	* 0.0	* 0.00
5	53.1	31.94	47.7	30.64	* 0.0	* 0.00
6	51.4	32.02	46.8	30.86	* 0.0	* 0.00
7	52.3	31.87	46.8	30.68	* 0.0	* 0.00
8	52.0	32.07	47.8	31.11	* 0.0	* 0.00
9	51.8	32.09	47.5	31.07	* 0.0	* 0.00
10	51.8	31.97	49.6	29.97	* 0.0	* 0.00
11	52.0	31.69	50.5	30.12	* 0.0	* 0.00
12	51.4	31.48	50.0	29.58	* 0.0	* 0.00
13	52.3	31.18	49.3	30.64	* 0.0	* 0.00
14	51.1	31.32	49.6	29.88	* 0.0	* 0.00
15	50.2	31.40	* 48.9	* 29.66	* 0.0	* 0.00
16	51.4	31.49	48.2	29.45	* 0.0	* 0.00
17	51.3	31.96	48.9	30.51	* 0.0	* 0.00
18	51.3	31.74	47.8	30.94	* 0.0	* 0.00
19	51.4	30.90	48.0	30.58	* 0.0	* 0.00
20	51.4	28.38	48.7	29.79	* 0.0	* 0.00
21	50.5	30.39	49.6	31.01	* 0.0	* 0.00
22	50.9	31.08	48.2	30.53	* 0.0	* 0.00
23	51.8	31.06	* 0.0	* 0.00	* 0.0	* 0.00
24	53.6	30.24	* 0.0	* 0.00	* 0.0	* 0.00
25	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
26	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
27	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
28	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
29	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
30	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
31	* 0.0	* 0.00	0.0	0.00	* 0.0	* 0.00
MEANS	51.9	31.39	48.5	30.47	0.0	0.00
OBSVNS.	23	23	21	21	0	0
YRLY.MEANS..					50.3	31.09
MAXIMUM	53.6	32.09	50.5	31.11	0.0	0.00
MINIMUM	50.2	28.38	46.8	29.45	0.0	0.00
STD.DEV.	.98	.838	1.12	.514	0.00	0.000

CAPE BEALE 48 47 12 N 125 12 53 W

	JANUARY		FEBRUARY		MARCH	1974
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
2	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
3	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
4	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
5	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
6	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
7	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
8	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
9	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
10	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
11	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
12	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
13	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
14	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
15	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
16	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
17	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
18	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
19	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
20	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
21	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
22	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
23	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
24	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
25	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
26	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
27	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
28	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
29	* 0.0	* 0.00	0.0	0.00	* 0.0	* 0.00
30	* 0.0	* 0.00	0.0	0.00	* 0.0	* 0.00
31	* 0.0	* 0.00	0.0	0.00	* 0.0	* 0.00
MEANS	0.0	0.00	0.0	0.00	0.0	0.00
OBSVNS.	0	0	0	0	0	0
MAXIMUM	0.0	0.00	0.0	0.00	0.0	0.00
MINIMUM	0.0	0.00	0.0	0.00	0.0	0.00
STD.DEV.	0.00	0.000	0.00	0.000	0.00	0.000

CAPE BEALE 48 47 12 N 125 12 53 W

	APRIL		MAY		JUNE	1974
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	48.6	30.28	* 0.0	* 0.00
2	* 0.0	* 0.00	48.0	30.77	* 0.0	* 0.00
3	* 0.0	* 0.00	48.7	29.35	* 0.0	* 0.00
4	* 0.0	* 0.00	50.4	29.61	* 0.0	* 0.00
5	* 0.0	* 0.00	48.4	29.89	* 0.0	* 0.00
6	* 0.0	* 0.00	* 49.3	* 29.99	* 0.0	* 0.00
7	48.0	28.70	50.2	30.08	* 0.0	* 0.00
8	47.7	28.62	* 49.4	* 30.34	* 0.0	* 0.00
9	47.8	28.42	48.6	30.60	* 0.0	* 0.00
10	47.7	28.33	50.7	31.16	* 0.0	* 0.00
11	48.2	25.02	49.6	29.48	* 0.0	* 0.00
12	50.0	29.10	49.6	29.92	* 0.0	* 0.00
13	49.3	30.65	47.7	30.73	* 0.0	* 0.00
14	50.0	30.07	* 0.0	* 0.00	* 0.0	* 0.00
15	* 49.3	* 29.70	* 0.0	* 0.00	* 0.0	* 0.00
16	* 48.7	* 29.33	* 0.0	* 0.00	* 0.0	* 0.00
17	48.0	28.96	* 0.0	* 0.00	* 0.0	* 0.00
18	48.0	28.72	* 0.0	* 0.00	* 0.0	* 0.00
19	47.8	29.29	* 0.0	* 0.00	* 0.0	* 0.00
20	47.7	29.31	* 0.0	* 0.00	* 0.0	* 0.00
21	46.8	30.67	* 0.0	* 0.00	* 0.0	* 0.00
22	48.2	29.78	* 0.0	* 0.00	* 0.0	* 0.00
23	48.9	30.58	* 0.0	* 0.00	* 0.0	* 0.00
24	* 48.6	* 30.60	* 0.0	* 0.00	* 0.0	* 0.00
25	48.2	30.62	* 0.0	* 0.00	* 0.0	* 0.00
26	48.6	30.78	* 0.0	* 0.00	* 0.0	* 0.00
27	49.1	29.75	* 0.0	* 0.00	* 0.0	* 0.00
28	50.0	29.80	* 0.0	* 0.00	* 0.0	* 0.00
29	50.4	30.68	* 0.0	* 0.00	* 0.0	* 0.00
30	48.9	30.13	* 0.0	* 0.00	* 0.0	* 0.00
31	0.0	0.00	* 0.0	* 0.00	0.0	0.00
MEANS	48.5	29.43	49.1	30.17	0.0	0.00
OBSVNS.	21	21	11	11	0	0
MAXIMUM	50.4	30.78	50.7	31.16	0.0	0.00
MINIMUM	46.8	25.02	47.7	29.35	0.0	0.00
STD.DEV.	.96	1.307	1.01	.588	0.00	0.000

CAPE BEALE   48 47 12 N   125 12 53 W

	JULY		AUGUST		SEPTEMBER 1974	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
2	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
3	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
4	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
5	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
6	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
7	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
8	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
9	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
10	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
11	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
12	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
13	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
14	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
15	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
16	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
17	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
18	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
19	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
20	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
21	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
22	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
23	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
24	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
25	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
26	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
27	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
28	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
29	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
30	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
31	* 0.0	* 0.00	* 0.0	* 0.00	0.0	0.00
MEANS	0.0	0.00	0.0	0.00	0.0	0.00
OBSVNS.	0	0	0	0	0	0
MAXIMUM	0.0	0.00	0.0	0.00	0.0	0.00
MINIMUM	0.0	0.00	0.0	0.00	0.0	0.00
STD.DEV.	0.00	0.000	0.00	0.000	0.00	0.000

CAPE BEALE 48 47 12 N 125 12 53 W

	OCTOBER		NOVEMBER		DECEMBER	1974
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	48.9	31.18	49.8	30.90
2	* 0.0	* 0.00	48.4	31.18	50.0	30.56
3	* 0.0	* 0.00	48.2	31.23	49.8	30.33
4	* 0.0	* 0.00	48.2	30.93	49.6	29.73
5	* 0.0	* 0.00	49.5	31.24	* 49.3	* 29.60
6	* 0.0	* 0.00	49.6	30.25	48.9	29.46
7	* 0.0	* 0.00	48.4	31.03	49.3	30.64
8	* 0.0	* 0.00	48.2	31.00	49.3	30.41
9	* 0.0	* 0.00	49.3	31.30	49.6	29.79
10	* 0.0	* 0.00	49.5	30.82	49.8	30.57
11	* 0.0	* 0.00	49.6	30.67	48.7	29.63
12	* 0.0	* 0.00	50.0	28.78	48.6	30.27
13	* 0.0	* 0.00	50.0	29.40	48.9	31.17
14	50.0	31.34	* 50.0	* 29.47	48.4	30.38
15	50.0	31.34	50.0	29.53	48.4	30.66
16	50.0	31.54	50.0	30.15	50.0	28.44
17	50.0	31.50	48.4	29.00	48.7	30.67
18	* 50.0	* 31.74	48.2	30.52	49.3	29.79
19	50.0	31.98	48.0	30.89	49.1	29.70
20	50.0	31.35	48.0	28.62	49.5	28.42
21	49.6	31.61	46.4	30.55	48.0	30.44
22	49.6	31.94	47.3	29.46	46.9	30.96
23	49.6	31.26	48.2	30.69	46.9	31.04
24	* 48.9	* 31.54	50.0	29.45	48.2	31.04
25	48.2	31.82	48.4	30.14	48.6	30.64
26	48.6	31.90	49.5	31.15	48.2	30.30
27	49.8	31.21	48.4	30.91	47.8	30.30
28	48.6	31.76	48.6	30.68	48.2	30.83
29	48.2	31.59	48.4	30.73	48.4	29.13
30	48.4	31.52	49.6	* 30.81	48.2	31.06
31	48.9	31.34	0.0	0.00	48.0	30.80
MEANS	49.3	31.56	48.8	30.41	48.8	30.27
OBSVNS.	16	16	29	28	30	30
YRLY.MEANS...						
MAXIMUM	50.0	31.98	50.0	31.30	50.0	31.17
MINIMUM	48.2	31.21	46.4	28.62	46.9	28.42
STD.DEV.	.72	.252	.91	.806	.83	.722

CAPE BEALE 48 47 12 N 125 12 53 W

	JANUARY		FEBRUARY		MARCH	1975
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	48.2	30.04	43.3	30.60	* 0.0	* 0.00
2	46.2	29.62	43.3	30.52	* 0.0	* 0.00
3	48.0	31.01	43.2	30.31	* 0.0	* 0.00
4	47.3	30.45	44.2	30.78	* 0.0	* 0.00
5	48.4	29.62	43.0	29.80	* 0.0	* 0.00
6	44.6	30.21	43.2	29.30	* 0.0	* 0.00
7	44.8	30.79	* 0.0	29.24	* 0.0	* 0.00
8	44.6	29.41	* 0.0	29.10	* 0.0	* 0.00
9	46.4	31.66	* 0.0	29.11	* 0.0	* 0.00
10	45.3	31.33	* 0.0	28.85	* 0.0	* 0.00
11	44.8	31.43	* 0.0	29.49	* 0.0	* 0.00
12	45.5	27.39	* 0.0	28.29	* 0.0	* 0.00
13	46.6	30.64	* 0.0	29.59	* 0.0	* 0.00
14	46.4	30.97	* 0.0	* 28.40	* 0.0	* 0.00
15	46.0	31.21	* 0.0	27.21	* 0.0	* 0.00
16	46.4	30.80	* 0.0	29.58	* 0.0	* 0.00
17	46.2	29.59	* 0.0	27.06	* 0.0	* 0.00
18	* 46.5	* 29.59	* 0.0	29.60	* 0.0	* 0.00
19	46.8	29.59	* 0.0	* 30.01	* 0.0	* 0.00
20	45.3	30.24	* 0.0	30.41	* 0.0	* 0.00
21	45.7	30.06	* 0.0	31.23	* 0.0	* 0.00
22	* 45.9	* 28.86	* 0.0	30.77	* 0.0	* 0.00
23	46.0	27.66	* 0.0	29.58	* 0.0	* 0.00
24	46.0	29.99	* 0.0	30.53	* 0.0	* 0.00
25	45.7	30.55	* 0.0	30.88	* 0.0	* 0.00
26	44.1	30.93	* 0.0	30.25	* 0.0	* 0.00
27	44.4	30.45	* 0.0	31.21	* 0.0	* 0.00
28	* 44.9	* 30.80	* 0.0	* 0.00	* 0.0	* 0.00
29	45.3	31.15	0.0	0.00	* 0.0	* 0.00
30	44.4	30.70	0.0	0.00	* 0.0	* 0.00
31	42.8	30.46	0.0	0.00	* 0.0	* 0.00
MEANS	45.8	30.28	43.4	29.73	0.0	0.00
OBSVNS.	28	28	6	25	0	0
MAXIMUM	48.4	31.66	44.2	31.23	0.0	0.00
MINIMUM	42.8	27.39	43.0	27.06	0.0	0.00
STD.DEV.	1.28	.988	.42	1.094	0.00	0.000

CAPE BEALE 48 47 12 N 125 12 53 W

	APRIL		MAY		JUNE	1975
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	50.2	31.55	55.8	28.77
2	46.0	30.84	47.7	31.06	53.8	30.86
3	46.4	30.77	46.9	29.95	51.8	30.54
4	45.1	30.88	49.3	30.93	50.7	30.21
5	44.8	30.81	48.2	30.81	51.8	31.11
6	45.9	30.96	48.4	30.73	51.4	31.56
7	46.4	30.64	48.2	31.45	49.6	31.88
8	46.8	31.05	49.8	31.52	50.0	31.82
9	47.5	31.19	52.3	31.40	* 50.9	* 31.16
10	47.8	31.26	50.5	31.38	51.8	30.50
11	48.6	31.23	51.8	31.24	* 51.1	* 31.07
12	49.3	31.41	52.3	31.33	50.4	31.64
13	46.8	31.74	53.4	31.47	51.4	31.07
14	47.5	31.64	50.9	31.06	50.2	31.54
15	48.6	31.53	* 51.5	* 30.60	50.5	31.40
16	48.0	30.89	52.2	30.14	50.2	31.88
17	49.6	31.29	50.2	30.02	50.5	31.75
18	48.4	31.22	50.0	30.85	49.5	32.14
19	46.9	31.30	50.0	30.85	50.4	31.61
20	47.3	31.71	* 50.1	* 30.12	49.8	31.86
21	46.6	31.73	50.2	29.38	50.5	31.86
22	* 46.5	* 31.46	50.2	30.56	50.4	31.50
23	46.4	31.19	51.1	29.66	51.8	30.30
24	46.4	31.76	49.6	31.36	52.2	27.45
25	47.3	31.79	* 50.7	* 31.12	50.2	31.37
26	47.8	31.73	51.8	30.88	51.1	31.32
27	* 47.7	* 31.55	50.0	31.48	51.6	31.12
28	47.7	31.37	52.2	30.68	52.0	30.92
29	48.2	32.28	50.7	31.37	54.1	30.12
30	50.2	30.73	55.0	31.30	55.6	29.12
31	0.0	0.00	54.0	31.58	0.0	0.00
MEANS	47.3	31.29	50.6	30.93	51.4	30.97
OBSVNS.	27	27	28	28	28	28
MAXIMUM	50.2	32.28	55.0	31.58	55.8	32.14
MINIMUM	44.8	30.64	46.9	29.38	49.5	27.45
STD.DEV.	1.29	.410	1.89	.607	1.65	1.073

CAPE BEALF 48 47 12 N 125 12 53 W

DATE	JULY TEMP	JULY SAL	AUGUST TEMP	AUGUST SAL	SEPTEMBER 1975 TEMP	SEPTEMBER 1975 SAL
1	52.0	30.61	53.6	31.74	52.2	31.98
2	53.4	31.00	53.2	31.77	53.6	32.16
3	50.0	31.55	53.6	31.66	55.4	31.99
4	51.4	31.87	53.6	31.55	55.4	32.26
5	50.2	31.87	* 53.7	* 31.23	55.4	31.94
6	50.9	31.67	53.8	30.90	53.6	* 32.04
7	50.5	30.96	53.6	30.92	* 54.1	* 32.15
8	53.2	31.30	53.6	30.71	54.7	32.26
9	55.0	30.35	54.1	30.60	53.6	* 0.00
10	53.4	30.97	54.5	30.56	52.3	* 0.00
11	53.6	27.42	54.5	31.09	* 52.5	* 0.00
12	54.9	31.34	54.1	31.00	52.7	* 0.00
13	50.4	31.75	55.0	31.00	* 52.3	* 0.00
14	51.6	31.66	55.2	30.76	52.0	* 0.00
15	55.4	30.58	55.2	30.84	51.6	* 0.00
16	51.1	31.69	* 55.0	* 30.64	51.3	* 0.00
17	51.3	31.78	54.9	30.44	* 51.5	* 0.00
18	52.9	31.55	53.6	32.68	51.8	* 0.00
19	53.4	31.25	51.8	* 0.00	52.9	* 0.00
20	53.2	31.44	51.6	0.00	52.5	* 0.00
21	53.2	31.57	52.3	0.00	52.5	* 0.00
22	55.4	31.54	51.4	0.00	52.5	* 0.00
23	55.9	31.47	53.4	0.00	52.3	* 0.00
24	52.9	31.64	51.8	0.00	52.2	* 0.00
25	51.8	31.59	51.8	0.00	51.6	* 0.00
26	55.4	31.22	52.3	* 0.00	51.6	* 0.00
27	53.6	31.56	52.7	31.17	* 0.0	31.25
28	50.4	31.88	52.2	32.83	* 0.0	31.13
29	50.7	31.96	53.2	32.18	* 0.0	31.17
30	* 52.0	* 31.90	53.6	32.47	* 0.0	31.24
31	53.2	31.84	53.6	30.84	0.0	0.00
MEANS	52.7	31.30	53.4	31.32	52.9	31.74
OBSVNS.	30	30	29	21	22	10
MAXIMUM	55.9	31.96	55.2	32.83	55.4	32.26
MINIMUM	50.0	27.42	51.4	30.44	51.3	31.13
STD.DEV.	1.77	.839	1.11	.720	1.30	.479

CAPE BEALE 48 47 12 N 125 12 53 W

	OCTOBER		NOVEMBER		DECEMBER 1975	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	51.4	31.19	51.8	30.72	48.0	29.86
2	51.3	31.28	51.8	30.58	48.2	27.79
3	50.5	31.18	52.5	27.57	48.2	30.00
4	50.5	31.23	52.7	27.54	46.9	30.03
5	50.4	28.48	* 52.2	* 28.41	46.2	29.33
6	50.2	31.11	* 51.7	* 29.28	46.2	28.80
7	51.3	31.26	51.1	30.15	46.4	27.43
8	51.8	31.50	50.9	29.71	47.5	25.95
9	53.1	30.78	50.5	30.14	46.4	25.07
10	54.1	29.89	49.6	27.31	45.1	28.80
11	53.2	30.51	49.6	28.32	42.8	* 30.74
12	53.2	30.81	49.6	27.10	44.6	32.68
13	* 53.2	* 30.69	50.0	27.87	45.1	* 0.00
14	53.2	30.57	48.6	28.21	45.3	* 0.00
15	53.4	29.38	* 49.0	* 29.08	45.7	* 0.00
16	* 53.4	* 28.25	49.5	29.95	43.2	* 0.00
17	53.4	27.11	47.8	27.95	44.8	* 0.00
18	52.7	29.32	* 47.8	* 28.47	44.6	* 0.00
19	51.8	28.02	47.8	28.99	43.9	* 0.00
20	51.8	30.97	47.8	29.72	43.3	* 0.00
21	52.3	30.49	48.4	30.09	44.6	* 0.00
22	52.0	30.28	48.6	29.34	45.1	* 0.00
23	51.8	30.11	49.5	27.69	45.0	32.48
24	51.8	30.33	49.8	28.82	45.9	32.08
25	51.4	30.20	49.6	29.57	45.9	32.95
26	51.8	29.81	49.3	29.33	45.9	28.95
27	50.0	28.51	48.0	29.96	* 46.1	* 30.50
28	* 50.3	* 28.10	46.9	30.23	46.4	32.06
29	50.5	27.68	47.7	30.14	46.8	30.33
30	49.6	30.13	46.0	29.75	44.6	32.48
31	49.6	28.45	0.0	0.00	44.8	* 32.70
MEANS	51.7	30.02	49.4	29.11	45.6	29.84
OBSVNS.	28	28	26	26	30	18
YRLY.MEANS..					50.1	30.48
MAXIMUM	54.1	31.50	52.7	30.72	48.2	32.95
MINIMUM	49.6	27.11	46.0	27.10	42.8	25.07
STD.DEV.	1.25	1.214	1.69	1.124	1.40	2.339

CAPE BEALF 48 47 12 N 125 12 53 W

	JANUARY		FEBRUARY		MARCH	1976
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	45.0	32.92	45.0	28.98	44.1	32.64
2	44.6	32.58	45.3	28.56	* 43.7	* 32.61
3	44.8	31.55	44.8	28.83	43.3	32.57
4	45.1	31.10	43.3	29.71	43.9	32.55
5	45.3	32.57	43.0	29.51	* 44.1	* 32.31
6	44.8	32.97	43.0	29.80	44.2	32.07
7	45.0	32.31	43.5	30.02	47.7	31.57
8	45.5	32.30	42.8	29.29	45.0	32.09
9	45.3	* 31.76	43.3	30.46	46.4	32.01
10	44.8	31.21	44.4	30.20	45.1	30.93
11	44.6	31.50	44.8	29.29	42.6	32.19
12	43.3	32.16	44.4	29.32	43.7	32.96
13	43.5	28.13	44.2	29.79	43.3	32.93
14	44.6	26.27	44.1	32.47	45.0	* 0.00
15	45.9	26.39	44.6	* 32.31	44.6	* 0.00
16	46.0	27.08	45.1	32.15	45.0	* 0.00
17	46.2	28.86	44.4	31.44	45.0	* 0.00
18	45.1	29.32	45.5	* 0.00	44.2	* 0.00
19	44.6	27.05	45.1	* 0.00	45.1	* 0.00
20	45.3	27.48	45.0	* 0.00	45.0	* 0.00
21	45.1	27.47	* 44.8	* 0.00	44.6	* 0.00
22	45.9	27.23	* 44.6	* 0.00	* 0.0	29.91
23	44.6	27.54	44.4	31.97	* 0.0	* 29.65
24	44.8	28.03	43.9	31.81	* 0.0	* 29.39
25	44.8	28.07	43.7	32.32	45.3	29.13
26	44.6	28.87	43.7	32.16	45.0	28.50
27	44.6	27.60	43.0	31.70	45.7	30.44
28	45.1	28.70	43.0	32.38	46.8	29.15
29	45.1	27.89	0.0	0.00	45.5	29.42
30	45.1	28.84	0.0	0.00	45.5	27.71
31	45.0	28.54	0.0	0.00	46.9	29.02
MEANS	45.0	29.42	44.1	30.55	44.9	30.94
OBSVNS.	31	30	26	22	26	19
MAXIMUM	46.2	32.97	45.5	32.47	47.7	32.96
MINIMUM	43.3	26.27	42.8	28.56	42.6	27.71
STD.DEV.	.61	2.222	.83	1.353	1.17	1.701

CAPE BEALE 48 47 12 N 125 12 53 W

	APRIL		MAY		JUNE	1976
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	47.8	29.19	52.2	29.28	50.0	29.34
2	47.5	29.11	50.0	29.42	50.7	29.31
3	47.5	29.21	50.7	30.06	* 51.1	* 29.74
4	47.3	28.50	49.3	30.17	51.6	30.18
5	47.5	28.97	49.3	30.75	54.9	27.24
6	48.0	29.37	49.3	30.96	56.1	26.96
7	47.5	29.53	49.3	30.96	55.2	27.50
8	48.0	29.52	* 48.7	* 31.02	53.8	28.96
9	46.9	29.36	48.2	31.07	52.0	29.21
10	46.9	29.44	48.2	30.66	52.0	29.99
11	47.5	29.32	48.7	30.83	50.0	30.31
12	46.8	29.46	49.1	30.74	49.6	30.66
13	47.8	28.98	50.4	30.56	51.1	30.60
14	46.0	28.74	* 49.8	* 30.69	50.7	30.36
15	46.9	30.40	49.3	30.82	50.0	28.67
16	* 47.2	* 29.96	49.1	30.67	51.4	30.41
17	47.5	29.52	* 49.8	* 30.44	51.4	30.24
18	47.5	30.10	50.5	30.21	52.9	29.27
19	* 47.1	* 29.74	50.9	30.15	52.9	29.52
20	46.8	29.37	50.9	30.94	53.1	29.57
21	47.5	29.80	51.1	30.57	54.9	28.29
22	46.2	29.92	50.9	30.52	53.2	29.00
23	47.1	29.66	49.8	30.68	52.9	29.71
24	46.0	28.99	50.5	30.34	52.9	29.62
25	46.4	30.07	49.3	30.94	50.7	31.42
26	47.5	30.71	* 49.1	* 30.78	51.1	31.19
27	* 47.5	* 30.59	48.9	30.62	52.9	30.69
28	47.5	30.47	* 0.0	* 0.00	52.9	30.35
29	51.1	30.21	* 0.0	* 0.00	53.2	27.98
30	51.1	29.00	* 0.0	* 0.00	52.7	30.91
31	0.0	0.00	49.3	30.00	0.0	0.00
MEANS	47.5	29.52	49.8	30.50	52.3	29.57
OBSVNS.	27	27	24	24	29	29
MAXIMUM	51.1	30.71	52.2	31.07	56.1	31.42
MINIMUM	46.0	28.50	48.2	29.28	49.6	26.96
STD.DEV.	1.18	.546	1.00	.467	1.68	1.156

CAPE BEALE 48 47 12 N 125 12 53 W

DATE	JULY TEMP	JULY SAL	AUGUST TEMP	AUGUST SAL	SEPTEMBER 1976 TEMP	SEPTEMBER 1976 SAL
1	54.3	30.96	56.3	30.22	52.7	30.51
2	54.7	30.64	54.7	30.25	54.7	29.70
3	53.2	30.47	54.0	30.44	54.3	29.65
4	52.9	30.45	55.2	30.27	52.0	29.48
5	54.7	30.41	51.4	30.96	53.6	28.96
6	51.8	30.58	53.2	31.03	52.3	30.75
7	52.5	30.24	52.9	30.70	52.2	30.70
8	53.4	29.84	53.2	30.47	* 52.4	31.02
9	52.5	30.36	53.2	30.51	52.7	30.83
10	53.4	30.02	51.8	30.58	52.7	30.74
11	54.7	29.85	51.8	30.62	52.7	30.75
12	55.4	29.57	* 51.4	* 30.64	* 52.6	* 30.77
13	55.8	29.68	51.1	30.65	52.5	30.80
14	56.3	27.98	51.4	31.02	52.0	30.87
15	57.0	28.99	53.4	30.39	51.6	30.83
16	56.8	28.52	53.2	29.89	* 52.0	* 30.67
17	* 53.8	* 29.97	* 52.6	* 29.89	* 52.3	* 30.51
18	50.7	31.42	* 52.0	* 29.89	52.7	30.35
19	51.4	31.01	51.4	29.89	52.0	30.80
20	52.9	31.00	52.5	30.74	* 52.5	* 30.66
21	52.0	30.98	52.2	30.85	53.1	30.51
22	52.7	30.81	52.2	30.61	52.5	30.53
23	52.7	30.54	51.4	30.53	52.7	* 0.00
24	* 53.5	* 30.40	* 51.9	* 30.58	52.7	* 0.00
25	54.3	30.26	52.3	30.64	53.2	* 0.00
26	54.0	30.11	52.3	30.50	52.7	* 0.00
27	* 54.1	* 30.13	49.6	30.42	51.4	* 0.00
28	54.3	30.16	51.6	30.59	* 51.3	* 0.00
29	51.8	30.83	53.2	30.10	51.1	* 0.00
30	52.9	30.60	* 54.0	* 29.83	50.9	* 0.00
31	53.8	30.81	54.9	29.56	0.0	0.00
MEANS	53.7	30.25	52.7	30.48	52.5	30.43
OBSVNS.	28	28	26	26	24	18
MAXIMUM	57.0	31.42	56.3	31.03	54.7	31.02
MINIMUM	50.7	27.98	49.6	29.56	50.9	28.96
STD.DEV.	1.61	.771	1.47	.350	.88	.581

CAPE BEALE 48 47 12 N 125 12 53 W

DATE	OCTOBER TEMP	OCTOBER SAL	NOVEMBER TEMP	NOVEMBER SAL	DECEMBER 1976 TEMP	DECEMBER 1976 SAL
1	* 50.9	* 0.00	* 0.0	30.21	* 0.0	* 31.30
2	50.9	30.98	* 0.0	31.07	* 0.0	31.25
3	50.0	31.58	* 0.0	30.67	* 0.0	31.21
4	50.9	31.60	* 0.0	31.05	* 0.0	31.03
5	50.5	31.60	* 0.0	30.14	* 0.0	31.14
6	* 50.5	* 31.49	* 0.0	30.52	47.3	31.02
7	50.5	31.38	* 0.0	* 30.87	47.7	28.80
8	50.9	31.19	* 0.0	31.22	* 47.4	* 30.21
9	50.7	31.22	* 0.0	31.14	47.1	31.63
10	51.4	28.40	* 0.0	31.34	* 47.4	* 31.39
11	51.4	30.29	* 0.0	31.44	47.7	31.15
12	* 50.9	* 30.49	* 0.0	* 31.44	47.1	31.13
13	50.5	30.68	* 0.0	31.44	* 47.2	* 30.41
14	50.7	30.78	* 0.0	31.08	* 47.4	* 29.68
15	50.0	30.90	* 0.0	30.97	47.5	28.95
16	49.6	30.68	* 0.0	28.28	47.8	30.04
17	49.1	30.73	* 0.0	* 29.77	47.7	29.98
18	48.7	30.93	* 0.0	31.26	46.0	30.60
19	49.1	30.99	* 0.0	31.35	46.9	31.85
20	49.1	31.14	* 0.0	31.12	47.5	31.11
21	48.7	31.33	* 0.0	30.89	48.2	31.37
22	48.7	31.13	* 0.0	30.65	48.4	31.05
23	48.7	30.86	* 0.0	30.78	47.5	31.00
24	48.9	29.71	* 0.0	30.31	47.5	31.28
25	49.1	30.77	* 0.0	30.43	47.5	30.52
26	49.1	30.88	* 0.0	31.09	48.4	30.07
27	49.1	30.94	* 0.0	31.20	48.4	30.83
28	* 49.1	* 30.93	* 0.0	31.31	47.1	31.05
29	49.1	30.91	* 0.0	31.24	47.5	30.58
30	* 0.0	* 29.42	* 0.0	31.34	47.5	31.01
31	* 0.0	27.93	0.0	0.00	47.1	30.99
MEANS	49.8	30.75	0.0	30.87	47.5	30.79
OBSVNS.	25	26	0	27	22	26
YRLY.MEANS..					49.1	30.34
MAXIMUM	51.4	31.60	0.0	31.44	48.4	31.85
MINIMUM	48.7	27.93	0.0	28.28	46.0	28.80
STD.DEV.	.94	.863	0.00	.643	.55	.718

CAPE BEALE 48 47 12 N 125 12 53 W

	JANUARY		FEBRUARY		MARCH	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	46.6	31.02	46.0	30.60	47.5	30.20
2	47.1	30.68	45.5	31.03	47.8	30.03
3	47.5	30.62	45.7	31.28	47.5	30.53
4	46.6	30.51	47.5	30.96	47.5	30.98
5	46.4	30.45	47.5	30.82	47.5	30.18
6	45.7	30.25	* 47.6	* 30.90	* 47.2	* 30.13
7	47.3	30.82	47.7	30.97	* 46.8	* 30.08
8	46.6	30.78	47.7	30.92	46.4	30.02
9	46.6	30.71	47.5	30.97	* 46.9	* 30.46
10	46.6	30.70	47.7	30.49	47.5	30.90
11	47.3	30.68	47.5	30.18	* 47.2	* 30.77
12	46.6	30.71	* 47.0	* 30.17	46.9	30.64
13	46.6	30.84	46.6	30.15	46.6	31.22
14	46.6	30.57	46.6	30.53	45.9	30.63
15	46.6	30.80	47.3	31.00	47.1	31.15
16	47.5	30.13	48.0	30.82	46.9	31.00
17	47.7	29.66	48.2	30.57	47.3	31.22
18	48.0	29.50	48.9	30.95	47.8	31.46
19	47.8	30.26	48.4	30.38	47.8	31.18
20	47.5	30.80	48.4	29.17	47.5	30.91
21	47.5	30.46	47.8	30.55	* 47.6	* 30.47
22	47.5	30.59	47.8	30.63	47.7	30.04
23	46.4	30.27	47.7	30.89	* 47.7	* 30.08
24	46.4	30.50	47.3	30.80	47.8	30.13
25	46.0	* 30.82	46.9	30.32	48.0	30.62
26	45.9	31.13	* 47.0	* 30.01	47.7	30.09
27	45.0	31.05	47.1	29.70	* 47.5	* 30.68
28	44.8	31.01	47.5	30.20	* 47.3	* 31.28
29	45.9	31.24	0.0	0.00	47.1	31.87
30	45.7	31.49	0.0	0.00	47.7	31.31
31	45.7	29.97	0.0	0.00	47.5	30.71
MEANS	46.6	30.61	47.4	30.60	47.3	30.74
OBSVNS.	31	30	25	25	23	23
MAXIMUM	48.0	31.49	48.9	31.28	48.0	31.87
MINIMUM	44.8	29.50	45.5	29.17	45.9	30.02
STD.DEV.	.81	.432	.82	.465	.52	.527

CAPE BEALE 48 47 12 N 125 12 53 W

	APRIL		MAY		JUNE	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	47.5	32.00	51.3	31.20	53.4	30.88
2	48.0	31.98	50.9	31.20	53.6	30.97
3	48.6	31.99	* 50.7	* 31.27	52.2	31.04
4	49.1	31.71	50.4	31.35	* 53.8	* 31.45
5	49.5	31.69	50.0	31.17	55.4	31.85
6	* 0.0	* 0.00	* 50.9	* 31.01	* 55.3	* 30.81
7	* 0.0	* 0.00	51.8	30.85	55.2	29.76
8	* 0.0	* 0.00	52.3	30.79	55.2	29.62
9	48.7	31.54	52.3	30.93	55.0	29.63
10	48.0	31.17	51.1	31.00	55.4	30.86
11	49.3	31.50	51.6	30.67	54.0	30.85
12	47.7	31.74	50.0	30.11	54.1	30.87
13	48.0	31.43	50.5	30.98	* 53.8	* 31.04
14	48.0	32.09	50.0	31.24	53.4	31.22
15	47.3	30.14	50.5	31.63	52.9	31.02
16	47.1	31.14	51.1	31.23	53.8	30.24
17	47.5	31.55	49.8	31.59	56.8	28.65
18	48.7	31.66	* 50.8	* 30.80	52.5	31.22
19	49.3	31.43	51.8	30.00	51.8	31.37
20	49.8	31.37	50.0	31.51	52.0	31.72
21	48.0	31.56	* 50.3	* 31.54	51.4	30.81
22	49.5	31.05	50.7	31.58	52.9	31.48
23	49.1	31.63	* 50.7	* 31.37	53.2	31.63
24	* 49.2	* 31.58	50.7	31.15	52.0	31.52
25	49.3	31.53	50.2	31.22	52.9	31.37
26	49.3	31.31	49.8	31.64	52.0	31.57
27	51.3	30.35	49.3	30.56	53.6	31.11
28	49.6	31.05	49.3	30.79	52.0	31.05
29	49.3	31.66	49.5	31.17	50.2	31.90
30	50.4	31.22	49.8	31.43	52.7	31.85
31	0.0	0.00	53.2	31.06	0.0	0.00
MEANS	48.8	31.44	50.7	31.08	53.3	30.97
OBSVNS.	26	26	26	26	27	27
MAXIMUM	51.3	32.09	53.2	31.64	56.8	31.90
MINIMUM	47.1	30.14	49.3	30.00	50.2	28.65
STD.DEV.	1.02	.454	1.01	.421	1.49	.782

CAPE BEALE 48 47 12 N 125 12 53 W

	JULY		AUGUST		SEPTEMBER 1977	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	52.7	31.21	* 53.1	* 31.95	55.2	31.38
2	53.6	31.53	52.9	32.05	52.9	31.57
3	52.7	31.69	* 52.9	* 32.10	* 53.5	* 31.60
4	51.8	31.80	52.9	32.15	* 54.1	* 31.63
5	* 52.2	* 31.81	52.9	32.18	54.7	31.67
6	52.5	31.83	53.1	32.30	55.4	31.04
7	54.5	31.94	53.1	32.07	58.3	30.66
8	56.7	30.72	54.7	31.86	55.8	31.39
9	56.7	31.00	53.4	32.04	57.0	31.19
10	51.3	31.83	54.3	32.12	55.2	31.51
11	50.7	32.34	52.2	32.31	52.9	31.74
12	52.9	32.11	53.4	32.26	53.6	31.53
13	51.6	32.40	* 55.0	* 31.68	53.2	31.59
14	54.7	31.78	56.7	31.09	54.7	31.47
15	54.7	31.64	55.8	* 0.00	* 54.7	* 31.60
16	52.7	31.20	55.6	* 0.00	54.7	31.73
17	52.5	32.39	55.9	* 0.00	53.8	31.24
18	52.7	31.90	55.2	* 0.00	52.9	31.23
19	53.2	32.06	56.3	* 0.00	52.9	30.86
20	53.8	31.89	* 56.1	* 0.00	52.9	31.74
21	56.8	31.16	* 55.9	* 0.00	54.7	32.04
22	55.6	31.40	55.8	* 0.00	52.9	31.48
23	52.9	32.01	* 54.9	* 0.00	53.6	31.22
24	57.2	31.64	* 53.9	* 0.00	54.7	31.74
25	55.4	31.47	52.9	* 0.00	54.7	31.68
26	52.9	31.48	* 52.9	* 0.00	55.0	31.80
27	52.7	32.17	52.9	31.32	* 0.0	* 0.00
28	51.1	31.99	52.9	31.39	* 0.0	* 0.00
29	52.0	31.06	52.3	31.55	* 0.0	* 0.00
30	53.8	31.63	52.3	31.55	* 0.0	* 0.00
31	53.2	31.86	* 53.8	* 31.46	0.0	0.00
MEANS	53.5	31.70	54.0	31.88	54.4	31.46
OBSVNS.	30	30	22	15	23	23
MAXIMUM	57.2	32.40	56.7	32.31	58.3	32.04
MINIMUM	50.7	30.72	52.2	31.09	52.9	30.66
STD.DEV.	1.77	.422	1.48	.398	1.41	.324

CAPE BEALE 48 47 12 N 125 12 53 W

	OCTOBER		NOVEMBER		DECEMBER 1977	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	* 52.0	* 31.05	48.9	29.03
2	52.3	31.75	* 51.7	* 31.07	* 48.7	* 29.90
3	52.0	31.67	51.4	31.08	48.4	30.77
4	52.0	31.66	* 0.0	* 0.00	47.7	31.33
5	52.3	31.61	* 0.0	* 0.00	47.8	31.17
6	52.5	31.69	* 0.0	* 0.00	47.5	29.44
7	52.0	31.55	49.8	30.56	* 47.0	* 30.12
8	52.2	31.57	50.2	31.36	46.6	30.79
9	* 51.3	* 31.63	49.3	30.02	49.1	30.81
10	50.5	31.69	* 49.9	* 29.62	47.5	29.59
11	51.1	31.67	50.5	29.21	* 47.9	* 29.36
12	51.1	31.39	49.6	29.53	* 48.3	* 29.12
13	50.7	31.10	50.7	31.68	48.7	28.89
14	50.7	31.37	* 0.0	* 0.00	48.9	27.83
15	50.9	31.01	* 0.0	* 0.00	47.7	26.93
16	50.7	30.96	* 0.0	* 0.00	46.6	28.45
17	50.0	31.30	49.1	30.26	47.5	27.76
18	49.6	31.41	* 48.5	* 30.73	* 47.7	* 27.74
19	49.5	31.45	47.8	31.20	47.8	27.72
20	* 49.6	* 31.31	47.5	31.00	44.8	27.55
21	* 49.7	* 31.17	46.0	31.06	46.6	28.60
22	49.8	31.02	46.0	29.28	46.6	28.82
23	49.3	31.18	46.0	31.11	46.4	28.83
24	49.3	30.57	* 46.8	* 30.36	45.7	28.58
25	49.5	31.75	47.5	29.62	46.4	27.82
26	49.1	31.73	47.5	29.49	45.7	27.78
27	50.7	31.12	47.5	27.92	45.5	27.42
28	* 51.3	* 31.01	48.0	30.85	44.6	27.79
29	* 51.8	* 30.89	48.7	31.00	46.4	28.49
30	52.3	30.78	49.3	31.30	46.4	29.57
31	52.3	31.04	0.0	0.00	43.9	29.03
MEANS	50.9	31.36	48.5	30.40	46.9	28.88
OBSVNS.	25	25	19	19	26	26
YRLY.MEANS					50.2	30.93
MAXIMUM	52.5	31.75	51.4	31.68	49.1	31.33
MINIMUM	49.1	30.57	46.0	27.92	43.9	26.93
STD.DEV.	1.16	.336	1.64	.987	1.37	1.249

Annual Graphs of the 7-day

Normally-Weighted Running Means

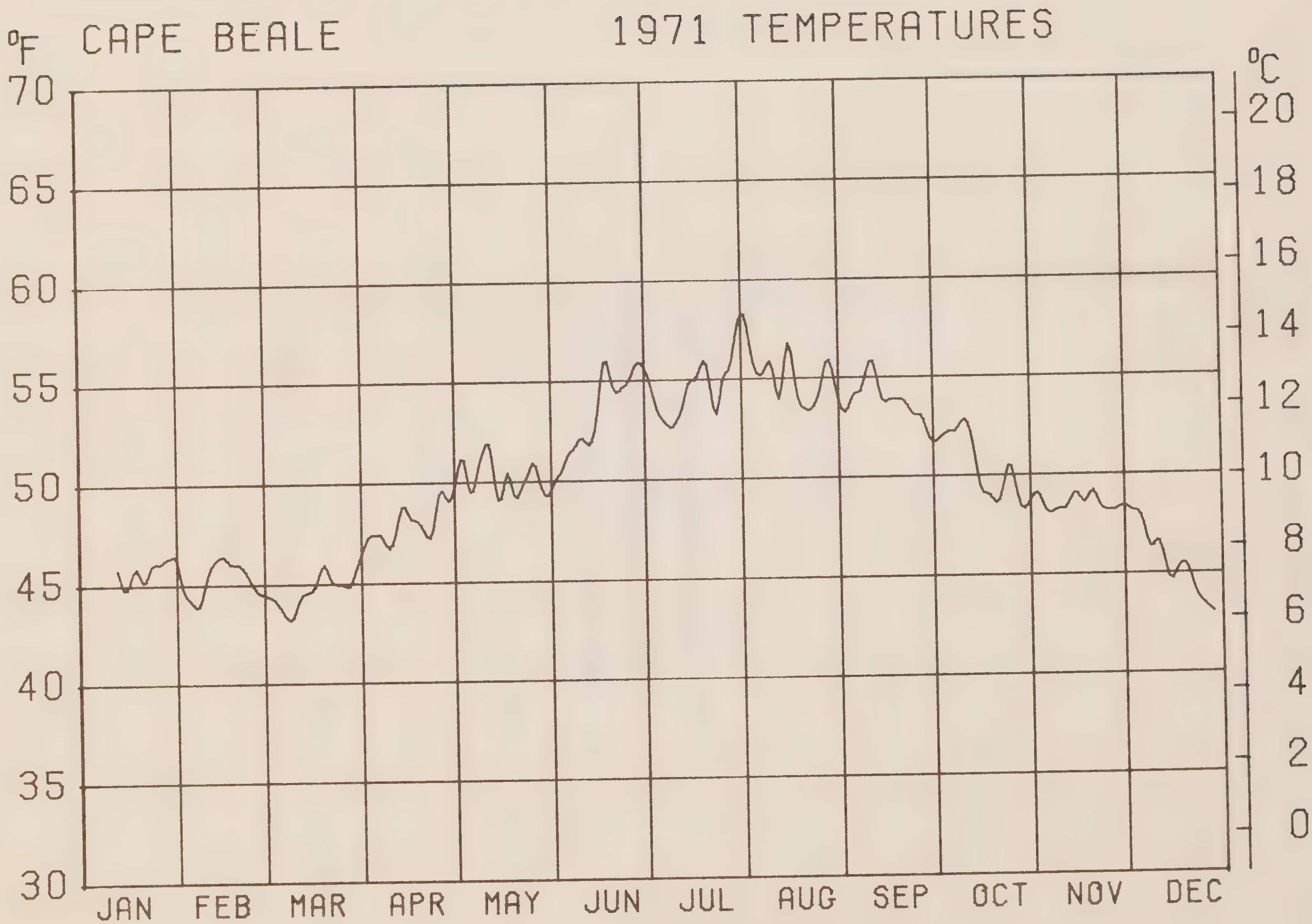
for Temperature and Salinity

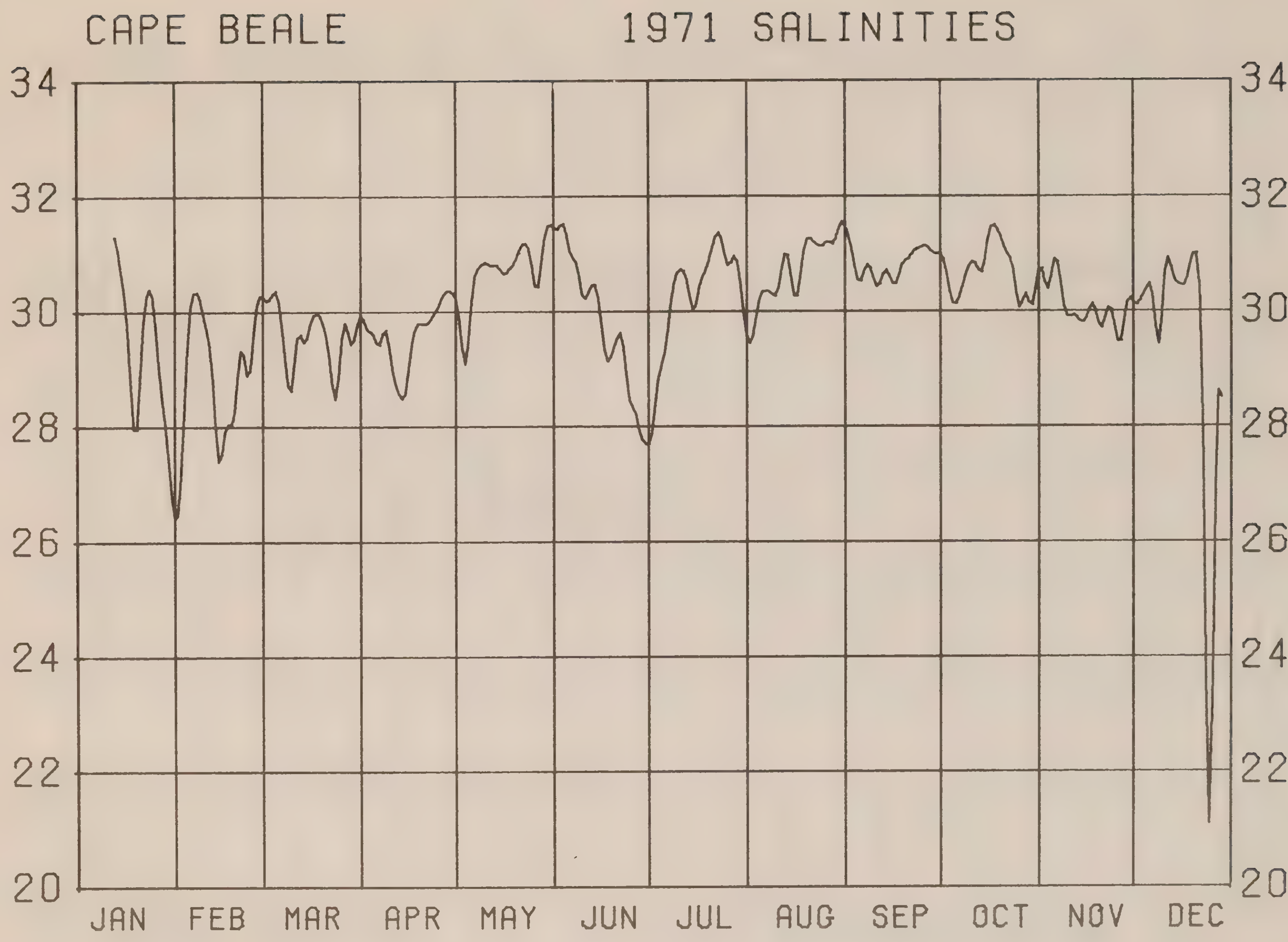
1971-1977

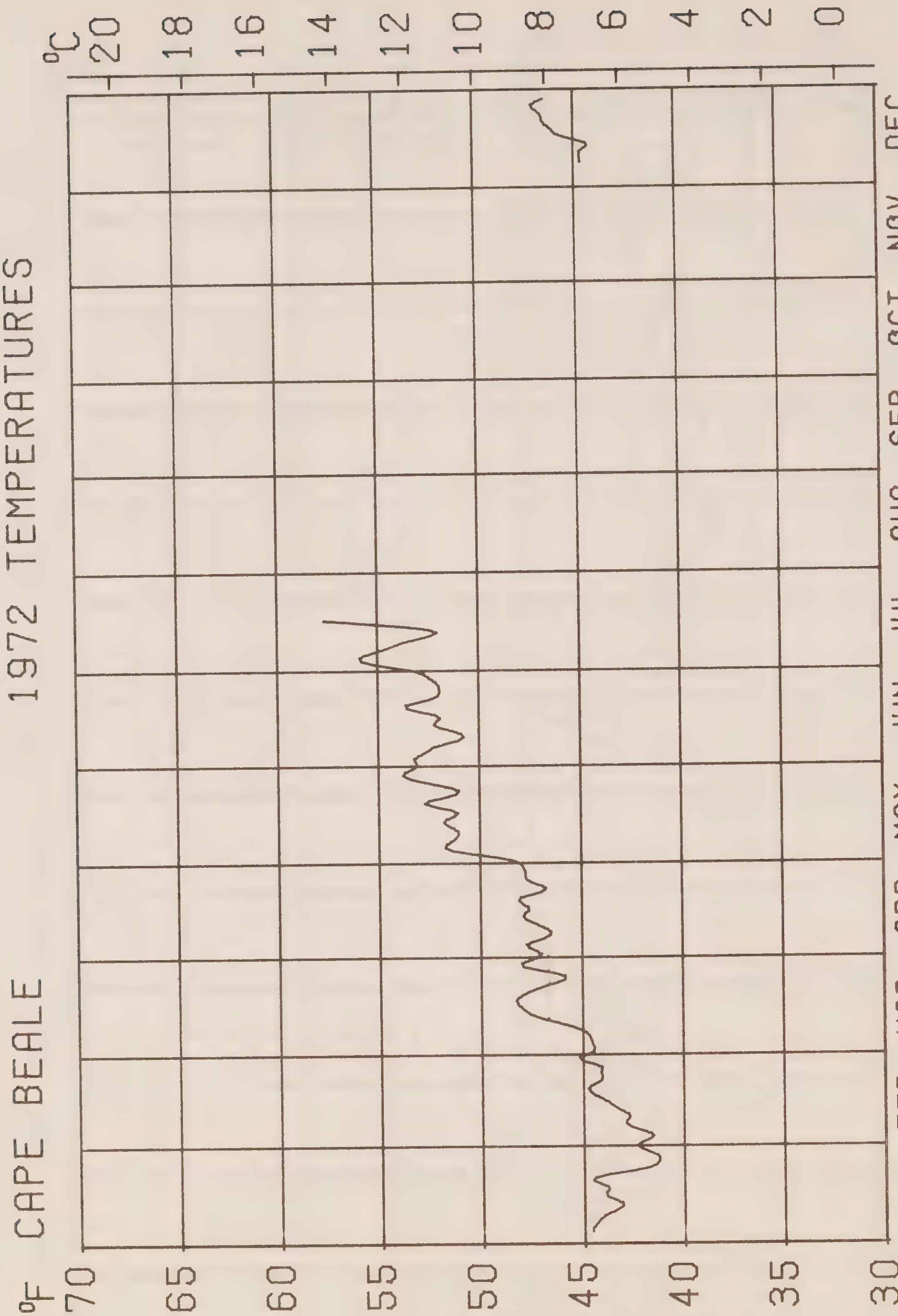
CAPE BEALE

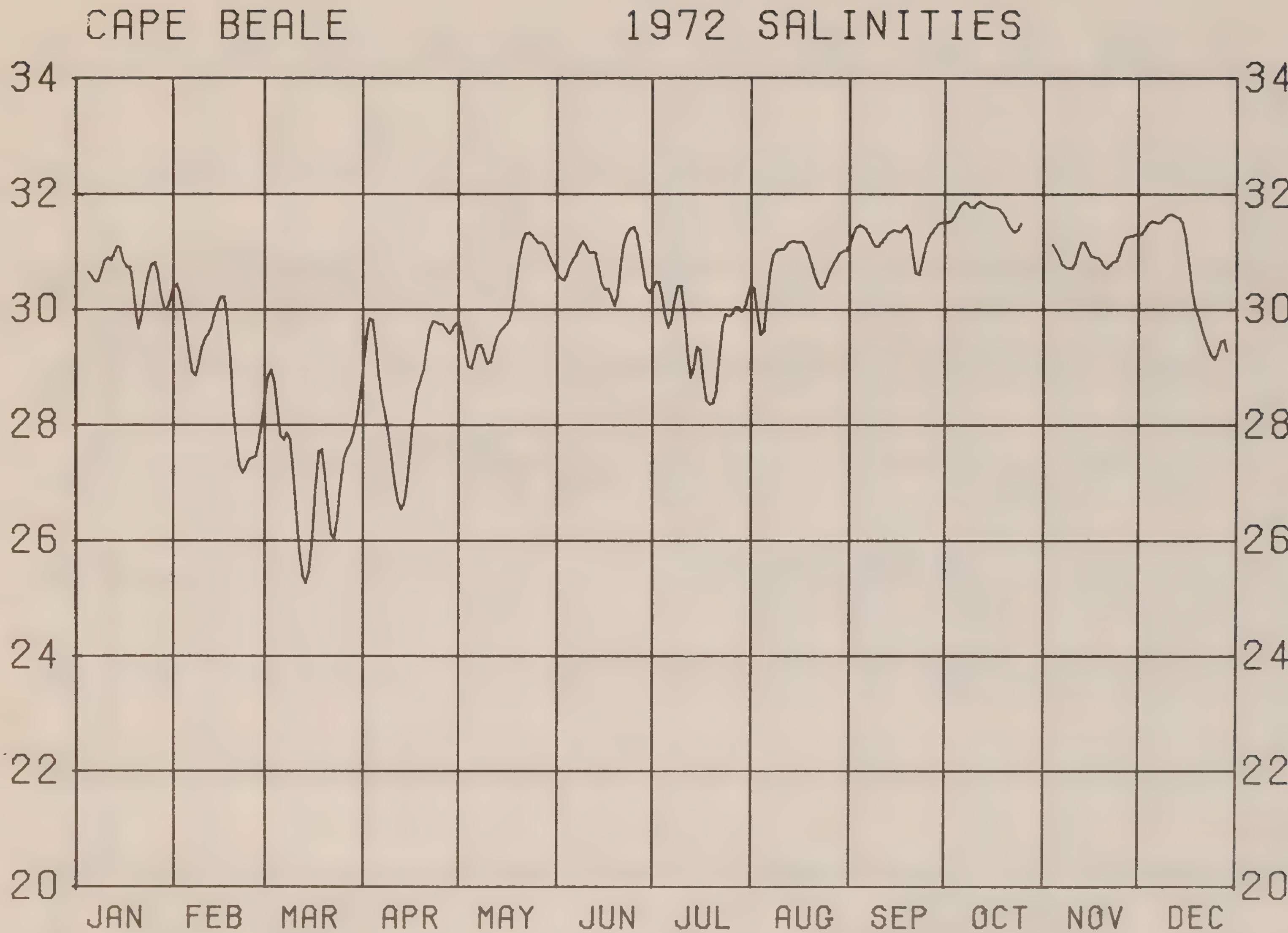
TEMP: Temperature (^{o}C and ^{o}F)

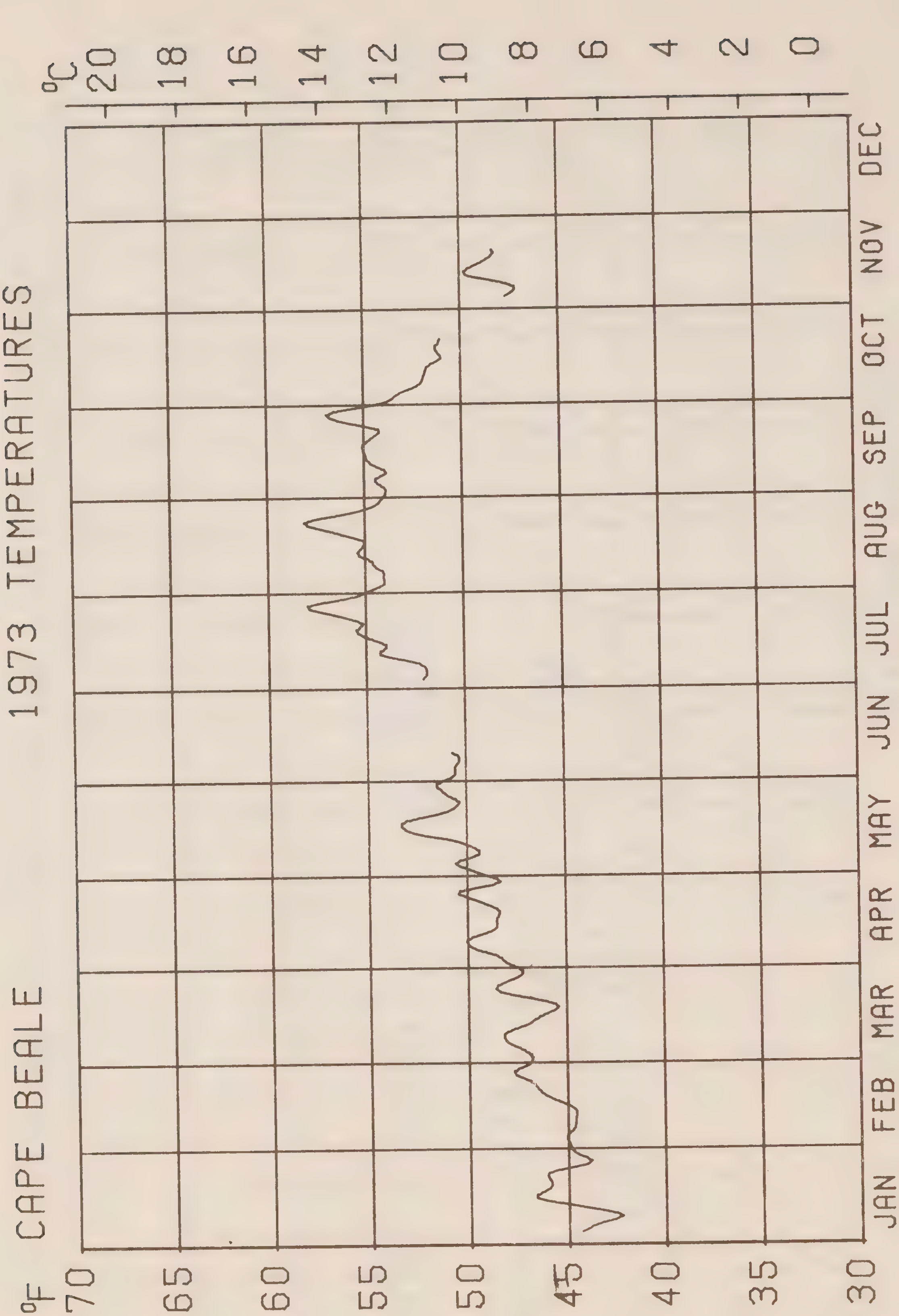
SAL: Salinity ($^{o}/oo$)

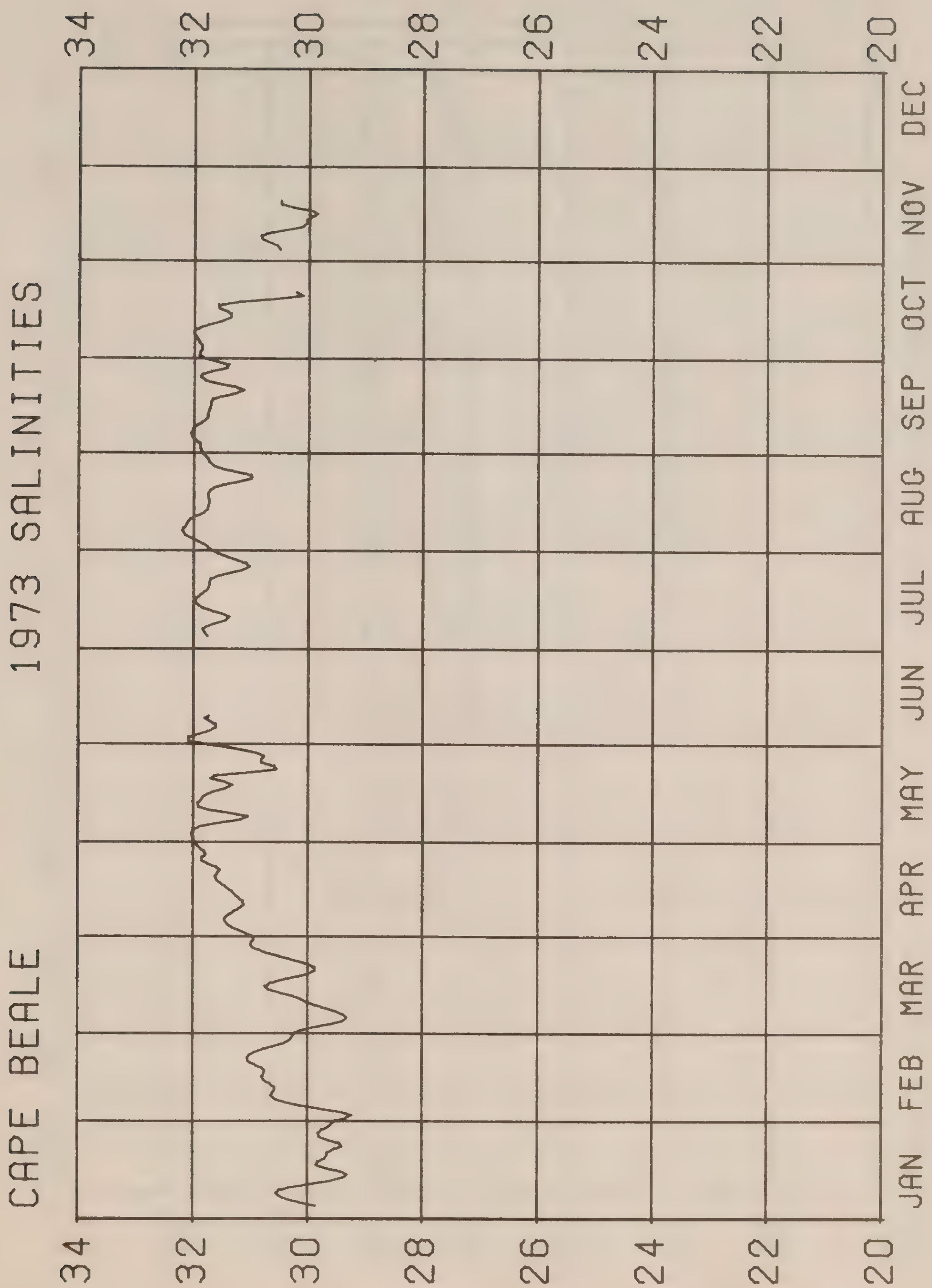

°F
CAPE BEALE
1971 TEMPERATURES
°C
70
65
60
55
50
45
40
35
30
20
18
16
14
12
10
8
6
4
2
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC


CAPE BEALE
1971 SALINITIES
34
32
30
28
26
24
22
20
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

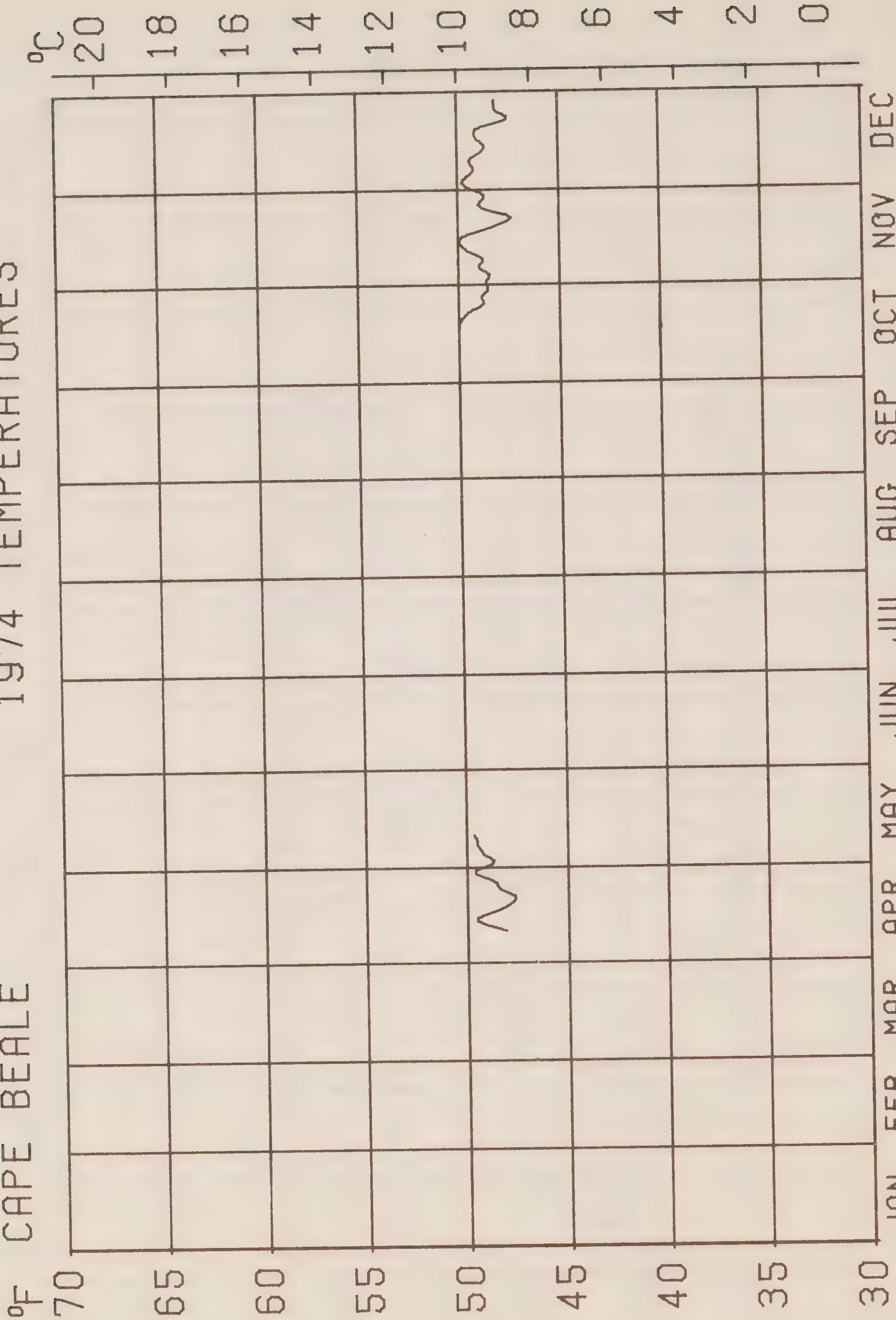

CAPE BEALE 1972 TEMPERATURES
°F
70
65
60
55
50
45
40
35
30
°C
20
18
16
14
12
10
8
6
4
2
0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

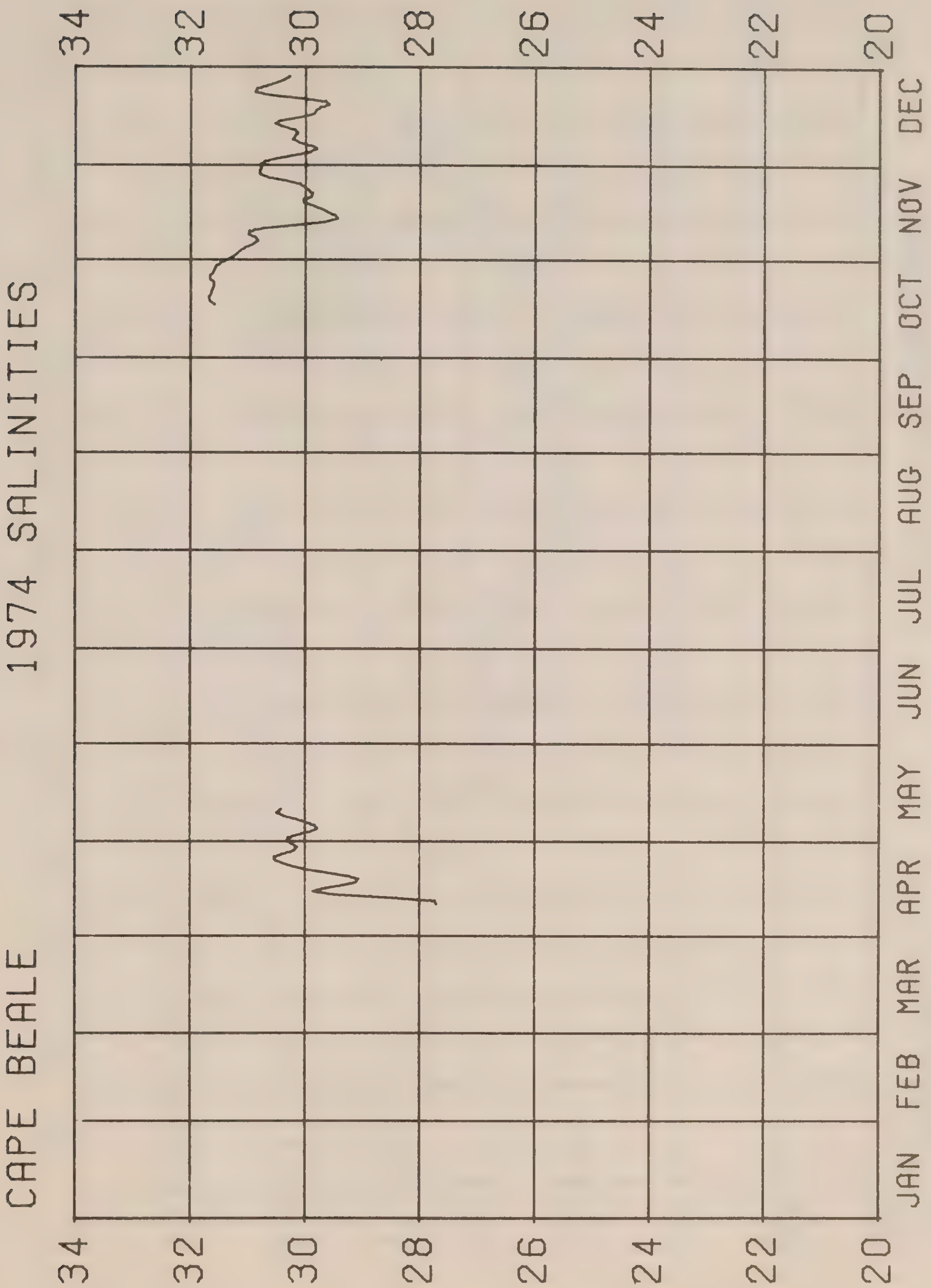

CAPE BEALE
1972 SALINITIES
34
32
30
28
26
24
22
20
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

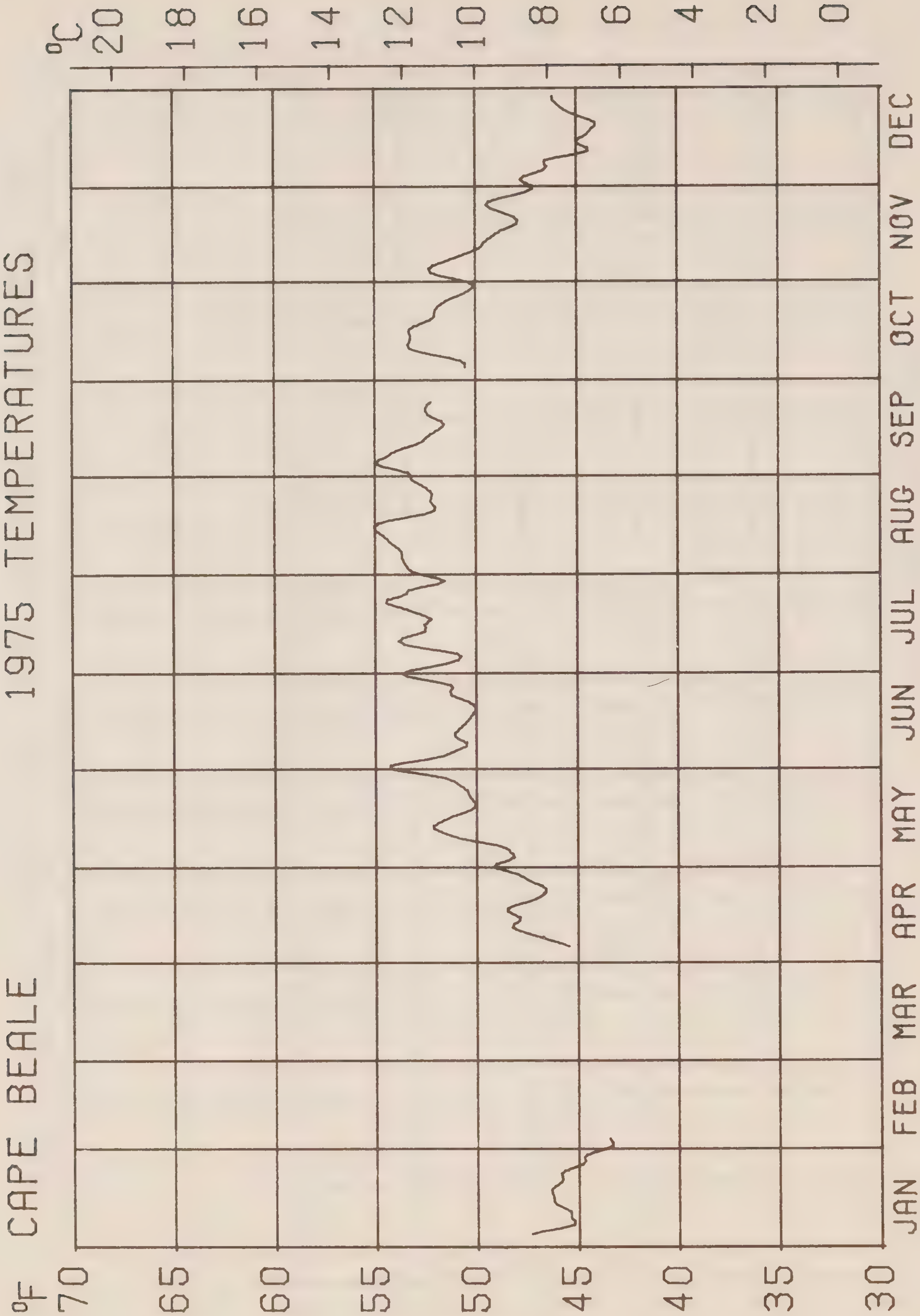

CAPE BEALE
1973 TEMPERATURES
°C
20
18
16
14
12
10
8
6
4
2
0
°F
70
65
60
55
50
45
40
35
30
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC


CAPE BEALE
1973 SALINITIES
34
32
30
28
26
24
22
20
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

CAPE BEALE 1974 TEMPERATURES




CAPE BEALE
1974 SALINITIES
34
32
30
28
26
24
22
20
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC


CAPE BEALE
1975 TEMPERATURES
°F
70
65
60
55
50
45
40
35
30
°C
20
18
16
14
12
10
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JAN
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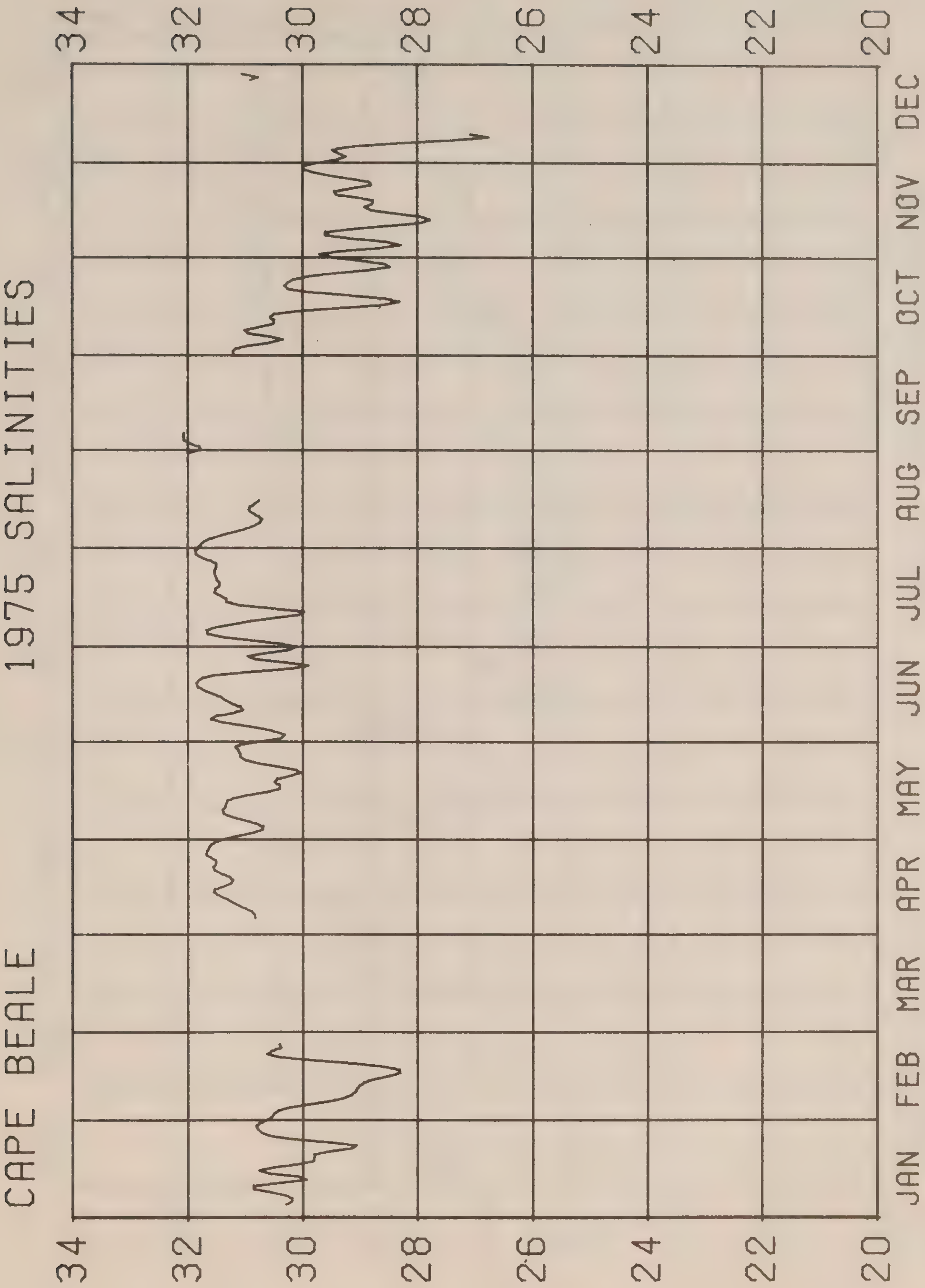
OCT
NOV
DEC


CAPE BEALE
1975 SALINITIES
34
32
30
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JAN
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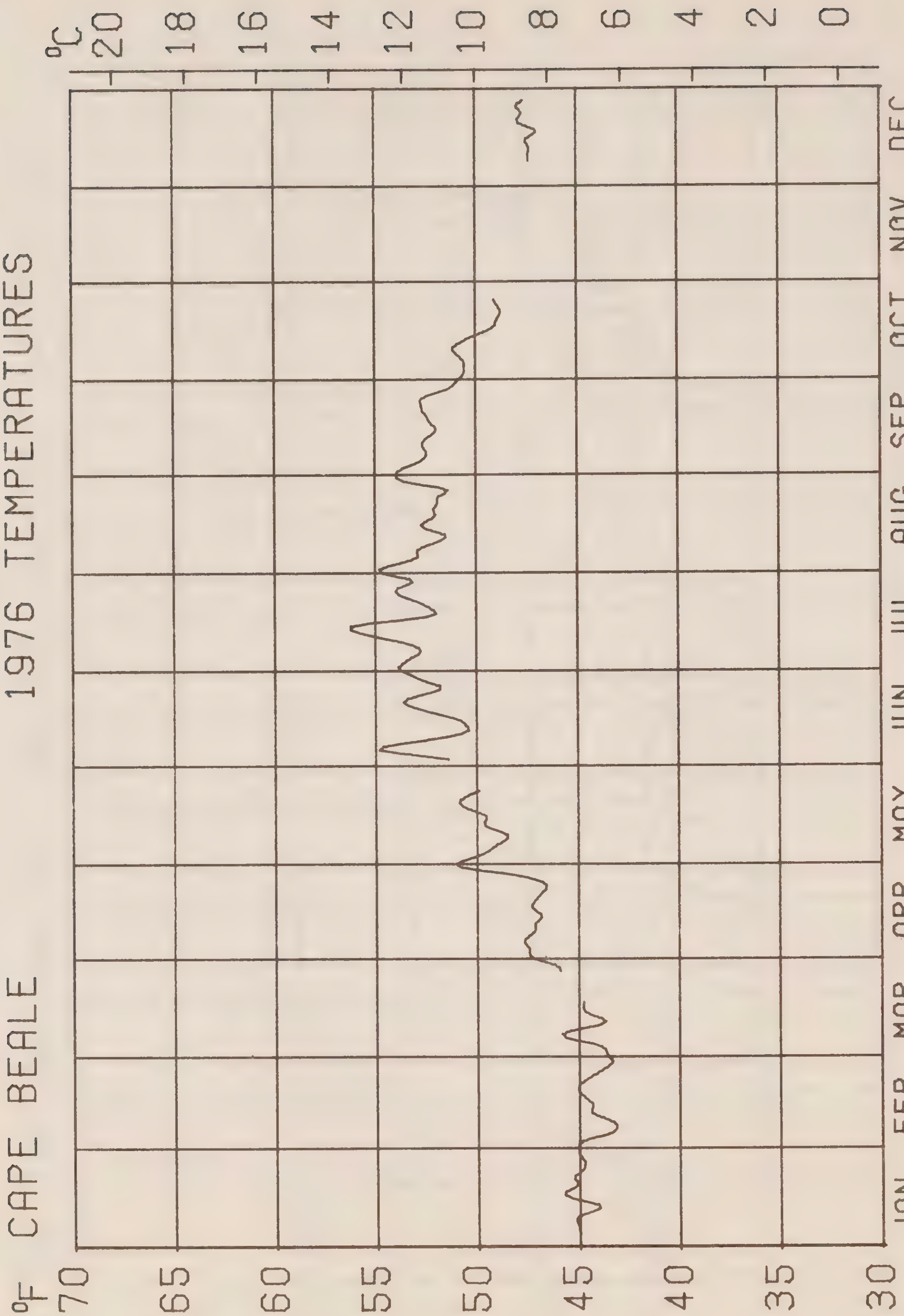
CAPE BEALE
1976 TEMPERATURES
°F
70
65
60
55
50
45
40
35
30
°C
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18
16
14
12
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JAN
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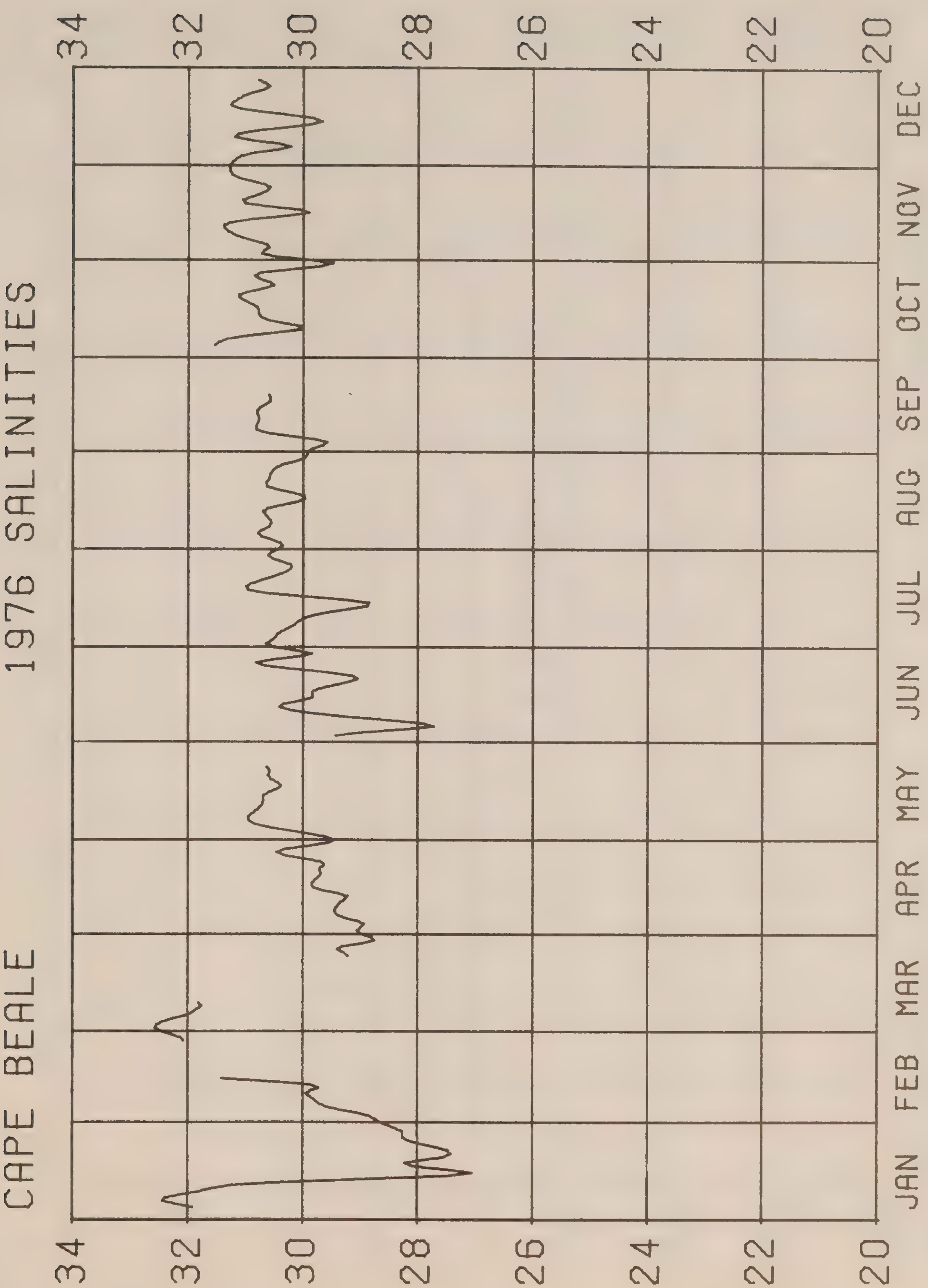
NOV
DEC


CAPE BEALE
1976 SALINITIES
34
32
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JAN
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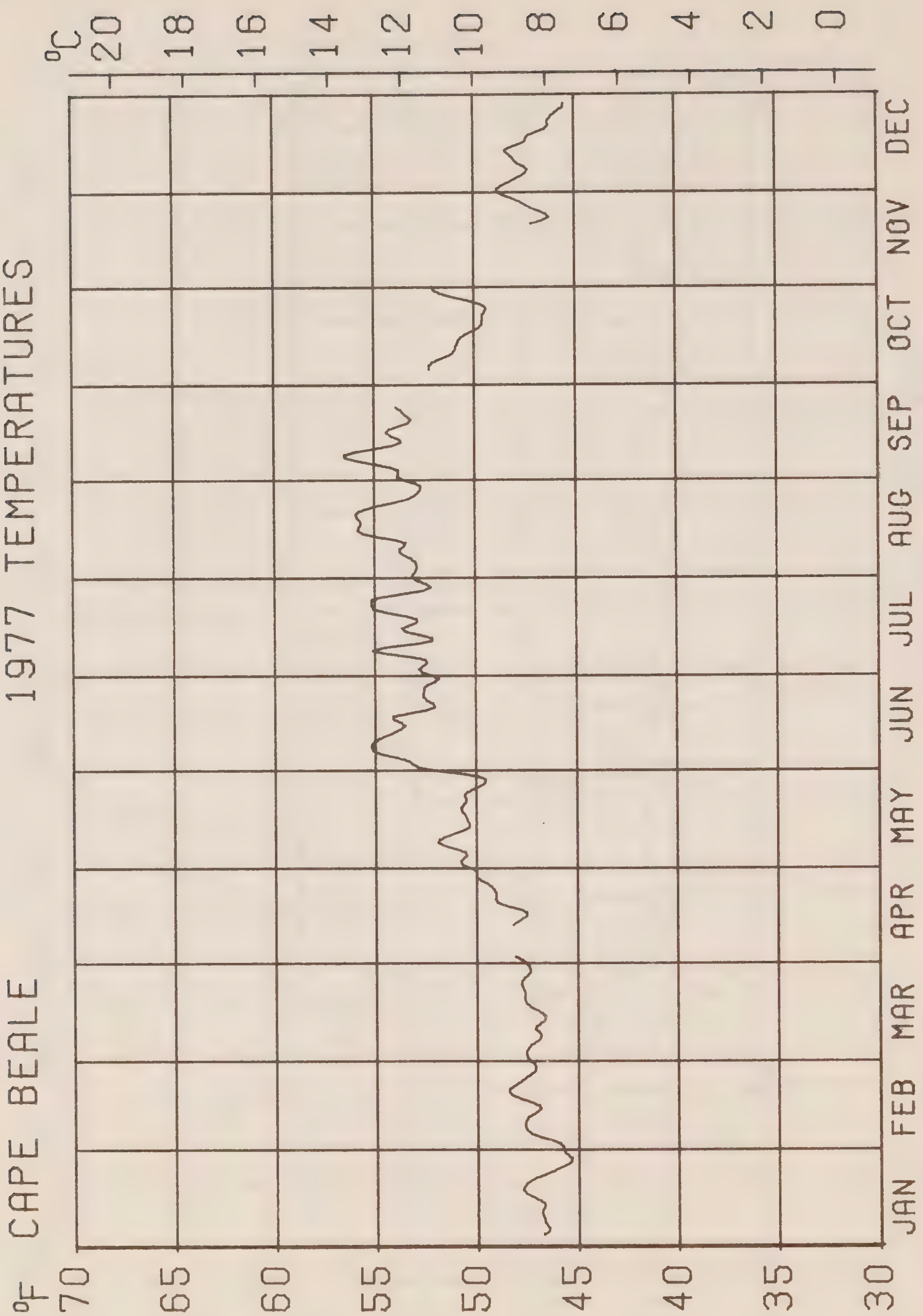
NOV
DEC


CAPE BEALE 1977 TEMPERATURES
°F
70
65
60
55
50
45
40
35
30
°C
20
18
16
14
12
10
8
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JAN
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OCT
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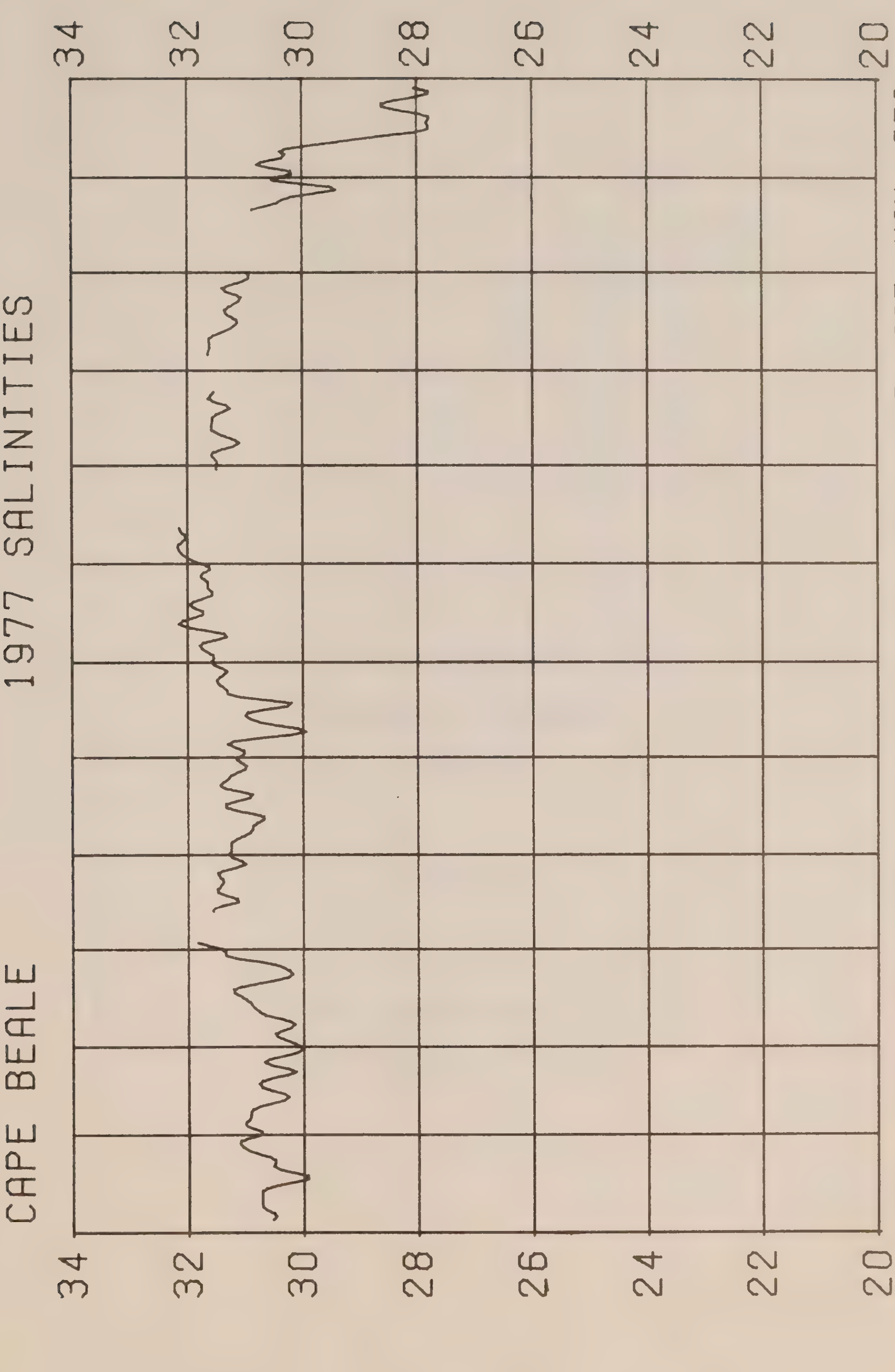
DEC


CAPE BEALE
1977 SALINITIES
34
32
30
28
26
24
22
20
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

Tabulations of Daily Sea-surface

Temperature and Salinity

1969-1977

BAMFIELD

TEMP: Temperature (^{o}F)

SAL: Salinity (^{o}/oo)

BAMFIELD 48 50 05 N 125 08 07 W

	JANUARY		FEBRUARY		MARCH	1969
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
2	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
3	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
4	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
5	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
6	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
7	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
8	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
9	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
10	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
11	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
12	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
13	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
14	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
15	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
16	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
17	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
18	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
19	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
20	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
21	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
22	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
23	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
24	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
25	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
26	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
27	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
28	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
29	* 0.0	* 0.00	0.0	0.00	* 0.0	* 0.00
30	* 0.0	* 0.00	0.0	0.00	* 0.0	* 0.00
31	* 0.0	* 0.00	0.0	0.00	* 0.0	* 0.00
MEANS	0.0	0.00	0.0	0.00	0.0	0.00
OBSVNS.	0	0	0	0	0	0
MAXIMUM	0.0	0.00	0.0	0.00	0.0	0.00
MINIMUM	0.0	0.00	0.0	0.00	0.0	0.00
STD.DEV.	0.00	0.000	0.00	0.000	0.00	0.000

BAMFIELD 48 50 05 N 125 08 07 W

	APRIL		MAY		JUNE	1969
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
2	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
3	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
4	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
5	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
6	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
7	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
8	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
9	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
10	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
11	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
12	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
13	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
14	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
15	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
16	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
17	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
18	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
19	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
20	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
21	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
22	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
23	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
24	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
25	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
26	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
27	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
28	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
29	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
30	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
31	0.0	0.00	* 0.0	* 0.00	0.0	0.00
MEANS	0.0	0.00	0.0	0.00	0.0	0.00
OBSVNS.	0	0	0	0	0	0
MAXIMUM	0.0	0.00	0.0	0.00	0.0	0.00
MINIMUM	0.0	0.00	0.0	0.00	0.0	0.00
STD.DEV.	0.00	0.000	0.00	0.000	0.00	0.000

BAMFIELD 48 50 05 N 125 08 07 W

	JULY		AUGUST		SEPTEMBER 1969	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	60.8	30.48	59.9	26.70
2	* 0.0	* 0.00	* 0.0	29.66	59.0	28.98
3	* 0.0	* 0.00	* 0.0	29.42	59.9	29.19
4	* 0.0	* 0.00	* 0.0	29.49	59.0	28.07
5	* 0.0	* 0.00	* 0.0	29.75	59.0	26.99
6	* 0.0	* 0.00	* 0.0	28.79	58.1	26.61
7	* 0.0	* 0.00	* 0.0	27.30	59.9	28.51
8	* 0.0	* 0.00	* 0.0	26.51	59.0	28.25
9	* 0.0	* 0.00	* 0.0	28.90	57.2	29.96
10	* 0.0	* 0.00	* 0.0	28.75	55.4	30.85
11	* 0.0	* 0.00	* 0.0	29.76	55.4	30.13
12	59.0	26.59	* 0.0	28.27	55.4	30.08
13	59.9	26.72	* 0.0	27.88	60.8	31.15
14	60.8	26.22	60.8	28.01	54.5	31.34
15	64.4	26.31	64.4	30.13	55.4	31.12
16	66.2	23.65	62.6	30.85	53.6	30.85
17	64.4	27.98	* 0.0	* 0.00	54.5	29.30
18	64.4	27.98	* 0.0	* 0.00	55.4	* 28.91
19	62.6	28.57	* 0.0	* 0.00	55.4	28.53
20	62.6	28.87	* 0.0	* 0.00	55.4	29.31
21	63.5	27.16	66.2	27.93	55.4	21.63
22	63.5	27.13	62.6	27.02	53.6	26.85
23	62.6	28.33	60.8	30.14	55.4	26.83
24	57.2	30.14	59.0	29.14	53.6	27.11
25	59.0	30.70	55.4	30.23	55.4	23.73
26	58.1	29.42	58.1	30.36	57.2	24.87
27	62.6	29.38	57.2	30.41	56.3	22.54
28	64.4	29.38	58.1	30.10	55.4	25.89
29	59.0	28.70	57.2	26.73	55.4	22.78
30	64.4	27.17	59.0	28.70	57.2	26.91
31	64.4	27.35	59.0	27.63	0.0	0.00
MEANS	62.1	27.89	60.1	28.98	56.6	27.76
OBSVNS.	20	20	15	27	30	29
MAXIMUM	66.2	30.70	66.2	30.85	60.8	31.34
MINIMUM	57.2	23.65	55.4	26.51	53.6	21.63
STD.DEV.	2.60	1.627	2.93	1.254	2.12	2.699

BAMFIELD 48 50 05 N 125 08 07 W

DATE	OCTOBER TEMP	OCTOBER SAL	NOVEMBER TEMP	NOVEMBER SAL	DECEMBER 1969 TEMP	DECEMBER 1969 SAL
1	55.4	27.15	51.8	29.44	48.2	29.96
2	55.4	25.48	51.8	29.32	49.1	29.95
3	57.2	27.70	50.0	29.67	49.1	28.61
4	57.2	22.78	51.8	29.44	38.3	28.52
5	51.8	22.17	48.2	29.61	48.2	29.63
6	52.7	23.84	49.1	26.57	48.2	29.83
7	52.7	25.52	50.0	29.97	49.1	28.99
8	52.7	28.55	50.0	27.08	48.2	30.47
9	52.7	28.05	50.0	26.23	48.2	29.82
10	53.6	27.27	50.9	24.04	50.0	30.03
11	53.6	26.12	50.0	21.79	47.3	30.04
12	55.4	28.99	51.8	23.82	46.4	30.63
13	* 54.0	* 28.44	54.5	25.59	49.1	30.53
14	52.7	27.89	51.8	26.41	48.2	29.65
15	53.6	28.60	48.2	23.71	47.3	27.48
16	59.0	28.31	49.1	26.92	46.4	28.93
17	54.5	28.97	48.2	27.12	48.2	28.29
18	52.7	27.84	49.1	28.41	49.1	28.92
19	52.7	30.21	49.1	25.97	48.2	29.94
20	53.6	29.71	50.9	29.12	48.2	27.72
21	53.6	31.01	49.1	26.11	47.3	* 28.69
22	52.7	28.75	49.1	26.66	* 47.3	29.66
23	51.8	29.90	50.0	22.80	47.3	28.85
24	51.8	28.74	49.1	24.12	46.4	26.51
25	52.7	30.33	49.1	20.85	46.4	27.06
26	52.7	30.76	50.0	27.44	48.2	27.96
27	51.8	29.74	50.0	28.63	43.7	28.94
28	51.8	30.56	50.0	28.94	48.2	29.42
29	51.8	30.79	49.1	28.88	50.9	29.52
30	51.8	30.61	48.2	29.65	48.2	29.10
31	53.6	28.51	0.0	0.00	* 46.8	* 29.42
MEANS	53.5	28.16	50.0	26.81	47.6	29.14
OBSVNS.	30	30	30	30	29	29
YRLY.MEANS...						
MAXIMUM	59.0	31.01	54.5	29.97	50.9	30.63
MINIMUM	51.8	22.17	48.2	20.85	38.3	26.51
STD.DEV.	1.82	2.326	1.42	2.548	2.24	1.043

BAMFIELD 48 50 05 N 125 08 07 W

	JANUARY		FEBRUARY		MARCH	1970
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	45.5	29.75	44.6	26.59	48.2	28.18
2	46.4	29.93	44.6	26.17	46.4	28.14
3	44.6	29.79	41.9	28.01	41.0	28.45
4	44.6	30.34	43.7	28.47	42.8	28.09
5	41.9	30.04	42.8	28.14	46.4	28.58
6	45.5	30.50	44.6	27.77	48.2	29.61
7	44.6	30.63	50.0	27.98	48.2	29.67
8	46.4	30.93	48.2	28.12	44.6	29.98
9	46.4	30.55	48.2	27.84	48.2	29.98
10	45.5	30.52	47.3	27.64	48.2	29.78
11	47.3	30.57	46.4	27.57	48.2	29.19
12	46.4	30.58	46.4	26.30	47.3	29.54
13	46.4	30.62	48.2	26.48	48.2	29.52
14	45.5	30.64	46.4	26.34	48.2	29.44
15	42.8	30.61	46.4	25.57	46.4	26.97
16	44.6	30.77	46.4	25.86	47.3	26.63
17	41.0	30.82	45.5	24.01	44.6	27.28
18	* 43.7	30.68	46.4	27.15	44.6	24.05
19	46.4	28.05	46.4	25.82	45.5	23.83
20	46.4	30.37	46.4	26.01	45.5	27.46
21	46.4	28.12	48.2	26.93	48.2	28.77
22	44.6	28.76	47.3	26.85	46.4	25.57
23	44.6	29.01	50.0	27.15	50.0	28.75
24	46.4	25.75	50.9	27.40	51.8	29.06
25	46.4	23.83	50.0	26.54	48.2	24.36
26	46.4	24.04	49.1	26.92	51.8	23.18
27	44.6	25.22	47.3	28.20	48.2	26.35
28	44.6	26.75	47.3	28.27	50.0	25.08
29	44.6	29.17	0.0	0.00	51.8	21.57
30	44.6	28.00	0.0	0.00	51.8	25.09
31	45.5	26.93	0.0	0.00	50.0	27.04
MEANS	45.2	29.11	46.8	27.00	47.6	27.39
OBSVNS.	30	31	28	28	31	31
MAXIMUM	47.3	30.93	50.9	28.47	51.8	29.98
MINIMUM	41.0	23.83	41.9	24.01	41.0	21.57
STD.DEV.	1.42	2.084	2.18	1.035	2.58	2.289

BAMFIELD 48 50 05 N 125 08 07 W

	APRIL		MAY		JUNE	1970
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	48.2	27.33	52.7	27.00	64.4	27.59
2	48.2	29.63	55.4	27.82	60.8	28.50
3	50.0	28.15	57.2	27.97	55.4	29.56
4	48.2	27.73	50.0	29.77	64.4	29.11
5	47.3	28.13	50.0	29.54	59.0	30.62
6	46.4	28.72	50.0	29.79	57.2	26.66
7	45.5	29.38	49.1	29.77	55.4	30.83
8	50.0	28.98	49.1	29.60	59.0	30.83
9	50.0	28.07	51.8	29.56	59.9	28.60
10	50.0	22.16	55.4	29.60	59.0	28.62
11	50.0	15.97	54.5	28.93	59.0	28.59
12	50.9	15.45	49.1	28.37	59.9	28.73
13	50.0	26.03	55.4	28.03	57.2	28.68
14	49.1	23.95	51.8	29.96	58.1	28.61
15	50.0	26.33	53.6	29.71	59.0	26.44
16	49.1	26.35	50.0	27.73	57.2	29.19
17	50.9	26.04	52.7	29.83	59.0	28.61
18	50.0	28.49	53.6	29.72	60.8	29.13
19	49.1	28.46	54.5	29.98	64.4	26.99
20	50.9	29.24	54.5	29.74	66.2	26.75
21	51.8	27.90	53.6	27.62	64.4	27.91
22	50.9	27.95	55.4	29.60	68.0	30.76
23	50.0	29.29	57.2	28.44	57.2	30.77
24	47.3	30.05	55.4	* 28.68	62.6	30.13
25	47.3	29.06	55.4	28.93	60.8	30.61
26	49.1	27.38	55.4	30.14	58.1	* 29.86
27	51.8	25.51	55.4	30.79	60.8	29.11
28	50.9	24.53	53.6	30.97	* 59.9	30.10
29	51.8	27.95	55.4	29.09	59.0	31.33
30	51.8	27.18	53.6	27.60	59.0	31.16
31	0.0	0.00	53.6	28.88	0.0	0.00
MEANS	49.5	26.71	53.4	29.15	60.2	29.12
OBSVNS.	30	30	31	30	29	29
MAXIMUM	51.8	30.05	57.2	30.97	68.0	31.33
MINIMUM	45.5	15.45	49.1	27.00	55.4	26.44
STD.DEV.	1.65	3.480	2.43	.999	3.15	1.417

BAMFIELD 48 50 05 N 125 08 07 W

DATE	JULY TEMP	JULY SAL	AUGUST TEMP	AUGUST SAL	SEPTEMBER 1970 TEMP	SEPTEMBER 1970 SAL
1	59.0	28.51	* 64.4	29.98	55.4	31.72
2	59.0	28.10	60.8	30.06	57.2	* 31.72
3	64.4	28.58	59.9	29.66	55.4	31.71
4	57.2	30.51	60.8	29.27	55.4	* 31.45
5	59.0	30.82	60.8	29.04	55.4	31.19
6	59.0	31.21	60.8	31.19	55.4	29.94
7	61.7	30.51	60.8	28.25	55.4	31.17
8	61.7	31.25	62.6	28.63	55.4	31.26
9	60.8	31.37	64.4	29.48	55.4	29.95
10	59.0	31.25	62.6	29.32	53.6	30.49
11	60.8	30.92	62.6	29.32	60.8	29.25
12	61.7	30.89	62.6	29.29	57.2	30.62
13	59.0	31.68	62.6	30.31	57.2	30.68
14	59.0	31.37	62.6	30.19	55.4	30.86
15	64.4	30.10	* 61.7	30.44	54.5	30.93
16	57.2	31.51	* 60.8	* 30.76	53.6	30.42
17	60.8	30.69	59.9	31.09	53.6	30.71
18	66.2	29.22	62.6	30.26	53.6	31.20
19	68.0	30.29	59.9	29.29	55.4	31.40
20	55.4	31.01	59.0	30.01	57.2	30.04
21	59.0	31.29	60.8	29.47	55.4	29.19
22	59.0	30.29	63.5	29.16	51.8	30.60
23	59.0	30.56	62.6	29.90	55.4	27.79
24	60.8	29.78	62.6	29.92	51.8	28.19
25	59.0	30.30	62.6	29.70	51.8	27.13
26	60.8	29.85	62.6	28.44	55.4	28.73
27	59.0	30.38	57.2	30.12	55.4	26.09
28	59.0	30.02	60.8	28.79	59.0	30.14
29	59.0	28.42	59.0	* 29.84	57.2	30.31
30	59.0	27.34	59.0	30.90	55.4	30.78
31	68.0	28.21	55.4	31.47	0.0	0.00
MEANS	60.5	30.20	61.1	29.76	55.4	30.09
OBSVNS.	31	31	28	29	30	28
MAXIMUM	68.0	31.68	64.4	31.47	60.8	31.72
MINIMUM	55.4	27.34	55.4	28.25	51.8	26.09
STD.DEV.	2.95	1.158	1.99	.801	1.96	1.393

BAMFIELD 48 50 05 N 125 08 07 W

	OCTOBER		NOVEMBER		DECEMBER	1970
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	57.2	30.37	51.8	30.79	43.7	29.22
2	57.2	30.35	51.8	30.92	42.8	29.95
3	57.2	30.58	50.0	31.03	42.8	30.33
4	51.8	31.37	51.8	* 31.08	42.8	30.17
5	55.4	31.32	51.8	31.12	46.4	30.01
6	57.2	30.53	50.0	30.64	46.4	29.62
7	51.8	31.04	50.0	30.68	46.4	29.70
8	51.8	30.78	50.0	28.02	46.4	29.95
9	55.4	30.73	50.0	27.81	42.8	28.36
10	51.8	30.69	48.2	29.60	42.8	28.53
11	53.6	31.14	50.0	26.48	42.8	26.44
12	51.8	31.12	50.0	17.39	44.6	29.35
13	53.6	31.31	50.0	28.05	46.4	26.06
14	51.8	31.72	48.2	29.32	46.4	26.09
15	51.8	30.80	48.2	28.30	46.4	28.13
16	51.8	30.93	50.0	28.85	44.6	27.15
17	51.8	30.33	50.0	30.86	44.6	25.87
18	51.8	31.47	50.0	30.89	41.0	25.75
19	51.8	29.96	48.2	24.27	44.6	26.37
20	51.8	30.17	46.4	24.28	44.6	26.13
21	50.0	29.66	* 0.0	* 0.00	42.8	26.59
22	48.2	* 29.28	* 0.0	* 0.00	44.6	27.79
23	48.2	* 28.90	* 0.0	* 0.00	42.8	27.51
24	41.0	28.52	* 0.0	* 0.00	42.8	27.35
25	48.2	24.71	* 0.0	30.86	44.6	28.47
26	48.2	28.89	44.6	30.88	46.4	28.61
27	50.0	29.80	46.4	30.83	44.6	28.08
28	50.0	24.71	44.6	31.09	44.6	28.05
29	50.0	* 26.73	46.4	29.53	44.6	28.55
30	50.0	* 28.76	42.8	29.56	44.6	26.57
31	51.8	30.79	0.0	0.00	41.0	28.54
MEANS	51.7	30.14	48.8	28.88	44.3	28.04
OBSVNS.	31	27	25	25	31	31
YRLY.MEANS..........					52.0	28.80
MAXIMUM	57.2	31.72	51.8	31.12	46.4	30.33
MINIMUM	41.0	24.71	42.8	17.39	41.0	25.75
STD.DEV.	3.33	1.731	2.43	3.116	1.62	1.452

BAMFIELD 48 50 05 N 125 08 07 W

	JANUARY		FEBRUARY		MARCH	1971
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	42.8	28.21	46.4	12.37	41.0	27.77
2	44.6	28.83	42.8	10.64	44.6	28.74
3	44.6	28.90	42.8	23.71	42.8	28.26
4	42.8	28.91	42.8	25.02	42.8	28.50
5	42.8	28.89	42.8	25.64	42.8	26.96
6	44.6	29.46	42.8	25.84	44.6	25.52
7	44.6	29.66	44.6	26.19	42.8	21.84
8	46.4	27.95	42.8	27.66	42.8	28.30
9	46.4	29.09	46.4	27.58	* 43.7	28.63
10	42.8	29.13	46.4	28.52	44.6	27.33
11	44.6	29.96	46.4	28.76	44.6	26.68
12	44.6	29.93	48.2	25.98	44.6	27.90
13	41.0	29.92	46.4	27.35	46.4	26.34
14	44.6	30.21	46.4	26.55	46.4	20.68
15	46.4	30.17	46.4	25.49	46.4	23.72
16	44.6	30.40	46.4	25.07	46.4	20.61
17	44.6	28.91	44.6	23.16	46.4	23.05
18	46.4	27.77	46.4	23.53	46.4	23.22
19	44.6	28.39	42.8	23.16	42.8	22.72
20	42.8	26.47	44.6	22.83	42.8	23.48
21	41.9	25.47	44.6	25.03	44.6	25.37
22	42.8	18.15	44.6	25.44	44.6	25.38
23	42.8	19.88	44.6	24.39	45.5	27.39
24	42.8	20.91	44.6	24.80	44.6	26.70
25	42.8	26.01	44.6	22.55	44.6	28.39
26	44.6	21.84	44.6	21.00	46.4	28.94
27	46.4	26.51	42.8	24.28	44.6	27.69
28	46.4	24.07	42.8	27.72	46.4	26.74
29	44.6	24.35	0.0	0.00	44.6	28.76
30	44.6	14.58	0.0	0.00	46.4	25.30
31	44.6	16.41	0.0	0.00	44.6	26.31
MEANS	44.2	26.43	44.7	24.30	44.6	26.04
OBSVNS.	31	31	28	28	30	31
MAXIMUM	46.4	30.40	48.2	28.76	46.4	28.94
MINIMUM	41.0	14.58	42.8	10.64	41.0	20.61
STD.DEV.	1.47	4.363	1.62	4.080	1.50	2.475

BAMFIELD 48 50 05 N 125 08 07 W

	APRIL		MAY		JUNE	1971
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	46.4	25.78	53.6	22.57	55.4	19.35
2	44.6	27.68	53.6	22.58	55.4	22.54
3	46.4	27.70	53.6	22.71	55.4	23.03
4	48.2	23.65	53.6	24.92	53.6	20.17
5	48.2	27.77	51.8	25.92	60.8	17.08
6	46.4	27.85	51.8	25.51	53.6	16.77
7	46.4	27.53	53.6	24.22	53.6	21.43
8	46.4	28.06	53.6	25.19	57.2	18.63
9	46.4	27.17	53.6	26.82	55.4	24.46
10	46.4	27.44	57.2	21.95	55.4	22.24
11	48.2	22.03	51.8	27.13	57.2	25.71
12	50.0	27.06	51.8	27.21	55.4	26.45
13	50.0	28.08	50.0	* 0.00	55.4	27.28
14	46.4	27.16	* 50.6	* 0.00	55.4	26.15
15	48.2	27.12	* 51.2	* 0.00	55.4	27.01
16	48.2	27.16	51.8	20.39	55.4	27.03
17	50.0	22.92	50.0	25.34	57.2	26.57
18	48.2	24.39	51.8	26.61	55.4	26.76
19	48.2	26.81	51.8	22.13	57.2	27.11
20	48.2	26.99	51.8	27.39	57.2	26.49
21	48.2	25.94	51.8	27.12	55.4	26.14
22	48.2	25.02	53.6	27.48	57.2	26.13
23	48.2	27.05	53.6	25.41	57.2	27.84
24	48.2	26.60	53.6	24.93	53.6	28.60
25	51.8	28.05	57.2	19.17	55.4	28.24
26	51.8	26.64	55.4	20.44	57.2	23.28
27	51.8	25.43	55.4	26.24	57.2	* 20.61
28	50.0	25.29	57.2	21.97	57.2	17.93
29	50.0	28.07	55.4	26.15	59.0	19.42
30	50.0	28.34	55.4	27.36	59.0	15.31
31	0.0	0.00	53.6	23.76	0.0	0.00
MEANS	48.3	26.56	53.4	24.59	56.2	23.63
OBSVNS.	30	30	29	28	30	29
MAXIMUM	51.8	28.34	57.2	27.48	60.8	28.60
MINIMUM	44.6	22.03	50.0	19.17	53.6	15.31
STD.DEV.	1.83	1.608	1.94	2.425	1.68	3.981

BAMFIELD 48 50 05 N 125 08 07 W

	JULY		AUGUST		SEPTEMBER 1971	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	59.0	16.53	62.6	25.10	57.2	29.59
2	59.0	16.81	62.6	24.39	55.4	29.58
3	57.2	22.99	60.8	25.52	55.4	29.80
4	57.2	22.88	64.4	25.64	55.4	29.09
5	57.2	24.29	64.4	25.07	57.2	29.98
6	59.0	21.76	57.2	28.10	57.2	29.13
7	59.0	25.44	60.8	28.03	57.2	28.49
8	59.0	23.85	71.6	29.35	55.4	26.78
9	55.4	26.24	64.4	28.65	57.2	29.05
10	53.6	24.89	60.8	27.57	55.4	29.58
11	55.4	25.91	60.8	24.62	55.4	27.50
12	60.8	25.70	60.8	28.13	55.4	29.89
13	64.4	24.22	59.0	29.38	55.4	27.42
14	64.4	24.02	57.2	28.57	53.6	24.49
15	62.6	25.01	62.6	27.23	55.4	27.42
16	57.2	25.94	62.6	27.21	55.4	29.89
17	59.0	22.19	59.0	27.94	55.4	28.94
18	59.0	22.07	59.0	26.11	55.4	28.24
19	62.6	22.64	59.0	26.09	55.4	29.43
20	64.4	20.92	59.0	30.37	55.4	* 28.93
21	62.6	21.44	60.8	30.32	57.2	28.42
22	57.2	21.06	60.8	* 26.84	57.2	29.98
23	62.6	23.34	59.0	23.36	55.4	29.96
24	64.4	25.06	62.6	28.49	57.2	30.05
25	62.6	24.89	62.6	27.28	55.4	29.87
26	62.6	23.87	60.8	27.23	55.4	29.59
27	62.6	25.43	64.4	26.45	55.4	29.59
28	62.6	23.98	62.6	23.16	55.4	30.14
29	66.2	24.46	62.6	22.76	57.2	29.89
30	62.6	24.48	62.6	25.82	55.4	29.35
31	64.4	25.10	60.8	29.58	0.0	0.00
MEANS	60.5	23.46	61.6	26.92	55.9	29.00
OBSVNS.	31	31	31	30	30	29
MAXIMUM	66.2	26.24	71.6	30.37	57.2	30.14
MINIMUM	53.6	16.53	57.2	22.76	53.6	24.49
STD.DEV.	3.26	2.344	2.74	2.081	.94	1.264

BAMFIELD 48 50 05 N 125 08 07 W

DATE	OCTOBER TEMP	OCTOBER SAL	NOVEMBER TEMP	NOVEMBER SAL	DECEMBER 1971 TEMP	DECEMBER 1971 SAL
1	55.4	27.34	50.0	26.24	46.4	26.43
2	55.4	29.60	50.0	28.76	46.4	29.14
3	55.4	29.96	50.0	27.19	46.4	29.10
4	55.4	29.69	50.0	24.60	44.6	29.04
5	60.8	29.50	46.4	27.75	44.6	27.18
6	60.8	29.70	46.4	27.75	44.6	28.68
7	57.2	28.50	46.4	27.81	42.8	28.88
8	57.2	28.08	* 46.4	30.25	42.8	28.85
9	55.4	27.60	46.4	30.36	44.6	28.71
10	53.6	28.57	46.4	25.80	41.0	28.13
11	55.4	27.09	46.4	22.35	41.0	28.12
12	55.4	27.10	46.4	20.46	42.8	28.38
13	53.6	28.34	48.2	22.31	42.8	28.44
14	55.4	29.32	48.2	27.82	42.8	28.80
15	53.6	28.87	46.4	28.05	42.8	28.52
16	50.0	30.37	48.2	* 27.73	42.8	28.96
17	55.4	27.36	46.4	27.41	42.8	27.09
18	50.0	30.53	46.4	28.23	41.0	29.27
19	51.8	30.52	46.4	28.42	42.8	29.28
20	53.6	29.15	46.4	28.28	41.0	29.28
21	50.0	29.09	46.4	28.72	42.8	30.10
22	51.8	26.42	46.4	27.27	42.8	29.95
23	* 50.9	25.16	46.4	26.66	42.8	29.81
24	50.0	26.39	46.4	25.36	42.8	29.78
25	55.4	26.58	46.4	25.51	41.0	29.10
26	46.4	27.58	46.4	25.49	41.0	29.24
27	46.4	27.63	46.4	26.82	42.8	29.24
28	50.0	28.76	46.4	26.73	42.8	28.26
29	50.0	27.60	46.4	26.72	42.8	28.12
30	50.0	28.09	46.4	26.44	42.8	28.20
31	55.4	27.60	0.0	0.00	42.8	28.24
MEANS	53.5	28.33	47.1	26.74	43.0	28.72
OBSVNS.	30	31	29	29	31	31
YRLY.MEANS........					51.1	26.23
MAXIMUM	60.8	30.53	50.0	30.36	46.4	30.10
MINIMUM	46.4	25.16	46.4	20.46	41.0	26.43
STD.DEV.	3.55	1.344	1.31	2.212	1.52	.820

BAMFIELD 48 50 05 N 125 08 07 W

DATE	JANUARY TEMP	JANUARY SAL	FEBRUARY TEMP	FEBRUARY SAL	MARCH TEMP	MARCH SAL 1972
1	42.8	* 28.28	39.2	30.13	42.8	* 0.00
2	41.0	28.33	41.0	30.24	42.8	* 0.00
3	42.8	29.24	41.0	29.83	42.8	* 0.00
4	42.8	29.32	41.0	29.67	42.8	* 0.00
5	42.8	28.93	41.0	28.29	42.8	* 0.00
6	42.8	28.81	42.8	28.39	44.6	* 0.00
7	42.8	28.98	42.8	28.30	44.6	* 0.00
8	42.8	28.01	42.8	28.01	44.6	* 0.00
9	42.8	28.96	42.8	28.12	46.4	* 0.00
10	42.8	27.96	* 0.0	28.21	44.6	* 0.00
11	42.8	30.32	* 0.0	* 0.00	44.6	* 0.00
12	42.8	30.40	* 0.0	* 0.00	44.6	* 0.00
13	42.8	30.44	* 0.0	* 0.00	44.6	* 0.00
14	42.8	28.78	* 0.0	* 0.00	44.6	* 0.00
15	42.8	29.03	44.6	27.61	44.6	* 0.00
16	42.8	29.48	44.6	25.03	42.8	* 0.00
17	44.6	29.74	44.6	26.24	42.8	* 0.00
18	44.6	29.89	44.6	26.10	44.6	* 0.00
19	44.6	29.83	46.4	26.26	44.6	* 0.00
20	42.8	23.73	42.8	25.89	44.6	* 0.00
21	44.6	22.30	42.8	* 0.00	46.4	* 0.00
22	44.6	22.36	42.8	* 0.00	44.6	* 0.00
23	42.8	24.57	42.8	* 0.00	42.8	* 0.00
24	39.2	27.34	42.8	* 0.00	42.8	* 0.00
25	39.2	27.43	42.8	* 0.00	42.8	* 0.00
26	39.2	28.69	42.8	* 0.00	42.8	* 0.00
27	39.2	28.84	42.8	* 0.00	42.8	* 0.00
28	35.6	29.21	42.8	* 0.00	46.4	* 0.00
29	39.2	29.84	42.8	* 0.00	46.4	* 0.00
30	39.2	30.14	0.0	0.00	46.4	* 0.00
31	41.0	29.82	0.0	0.00	46.4	* 0.00
MEANS	42.0	28.36	42.8	27.90	44.3	0.00
OBSVNS.	31	30	24	16	31	0
MAXIMUM	44.6	30.44	46.4	30.24	46.4	0.00
MINIMUM	35.6	22.30	39.2	25.03	42.8	0.00
STD.DEV.	2.12	2.219	1.50	1.614	1.35	0.000

BAMFIELD 48 50 05 N 125 08 07 W

	APRIL			MAY		JUNE	1972
DATE	TEMP		SAL	TEMP	SAL	TEMP	SAL
1	39.2	*	0.00	50.0	21.99	60.8	28.04
2	39.2	*	0.00	50.0	22.13	60.8	26.24
3	39.2	*	0.00	51.8	21.95	59.0	25.67
4	41.0	*	0.00	51.8	21.94	62.6	21.34
5	44.6	*	0.00	50.0	26.30	62.6	26.44
6	39.2	*	0.00	53.6	25.79	60.8	26.42
7	44.6	*	0.00	53.6	24.71	60.8	27.45
8	39.2	*	0.00	57.2	19.39	60.8	19.23
9	44.6	*	0.00	53.6	25.76	62.6	19.27
10	39.2	*	0.00	53.6	25.70	53.6	19.41
11	44.6	*	0.00	53.6	24.43	51.8	19.42
12	48.2	*	0.00	55.4	24.35	60.8	19.38
13	46.4	*	0.00	55.4	26.39	60.8	21.37
14	46.4	*	0.00	53.6	26.29	55.4	23.04
15	46.4	*	0.00	51.8	26.66	55.4	23.72
16	46.4	*	0.00	55.4	27.81	59.0	27.81
17	44.6	*	0.00	57.2	25.76	60.8	27.07
18	46.4	*	0.00	57.2	23.86	66.2	22.64
19	50.0	*	0.00	55.4	21.55	66.2	22.64
20	51.8	*	0.00	57.2	21.51	62.6	25.56
21	51.8	*	0.00	59.0	26.17	62.6	24.78
22	50.0	*	0.00	59.0	28.21	59.0	27.74
23	50.0	*	0.00	60.8	27.79	62.6	24.38
24	48.2	*	0.00	55.4	26.36	62.6	24.32
25	48.2	*	0.00	57.2	23.24	59.0	24.47
26	50.0	*	0.00	59.0	22.51	55.4	23.64
27	44.6	*	0.00	60.8	26.56	59.0	28.93
28	44.6	*	0.00	* 0.0	28.04	60.8	24.43
29	44.6	*	0.00	* 0.0	28.33	62.6	24.42
30	48.2	*	0.00	* 0.0	27.31	62.6	29.07
31	0.0		0.00	* 0.0	28.08	0.0	0.00
MEANS	45.4		0.00	55.1	25.06	60.3	24.28
OBSVNS.	30		0	27	31	30	30
MAXIMUM	51.8		0.00	60.8	28.33	66.2	29.07
MINIMUM	39.2		0.00	50.0	19.39	51.8	19.23
STD.DEV.	3.97		0.000	3.15	2.449	3.31	3.021

BAMFIELD 48 50 05 N 125 08 07 W

DATE	JULY TEMP	JULY SAL	AUGUST TEMP	AUGUST SAL	SEPTEMBER 1972 TEMP	SEPTEMBER 1972 SAL
1	59.0	27.70	59.0	* 0.00	* 0.0	* 0.00
2	60.8	27.54	60.8	* 0.00	60.8	27.75
3	57.2	28.85	57.2	* 0.00	59.9	28.80
4	60.8	* 0.00	57.2	* 0.00	59.0	29.24
5	60.8	* 0.00	60.8	* 0.00	57.2	30.24
6	59.0	* 0.00	62.6	* 0.00	57.2	30.89
7	57.2	* 0.00	62.6	* 0.00	57.2	30.46
8	55.4	* 0.00	60.8	* 0.00	54.5	31.03
9	57.2	* 0.00	60.8	* 0.00	58.1	31.08
10	59.0	* 0.00	62.6	* 0.00	57.2	30.92
11	57.2	* 0.00	57.2	* 0.00	59.9	30.72
12	59.0	* 0.00	55.4	* 0.00	59.0	30.19
13	57.2	* 0.00	57.2	* 0.00	59.0	29.79
14	59.0	* 0.00	57.2	* 0.00	59.9	29.49
15	57.2	* 0.00	55.4	* 0.00	59.0	29.86
16	64.4	* 0.00	57.2	* 0.00	57.2	29.24
17	66.2	* 0.00	59.0	* 0.00	56.3	30.61
18	64.4	* 0.00	55.4	* 0.00	55.4	30.75
19	66.2	* 0.00	55.4	* 0.00	53.6	30.77
20	66.2	* 0.00	57.2	* 0.00	53.6	30.13
21	64.4	* 0.00	57.2	* 0.00	51.8	29.96
22	64.4	* 0.00	57.2	* 0.00	51.8	30.59
23	64.4	* 0.00	57.2	* 0.00	51.8	30.72
24	59.0	* 0.00	57.2	* 0.00	51.8	29.45
25	66.2	* 0.00	55.4	* 0.00	53.6	27.52
26	64.4	* 0.00	59.0	* 0.00	53.6	* 27.84
27	57.2	* 0.00	59.0	* 0.00	53.6	28.16
28	59.0	* 0.00	* 0.0	* 0.00	51.8	30.39
29	59.0	* 0.00	* 0.0	* 0.00	54.5	28.36
30	66.2	* 0.00	* 0.0	* 0.00	55.4	26.45
31	66.2	* 0.00	* 0.0	* 0.00	0.0	0.00
MEANS	61.1	28.03	58.3	0.00	56.0	29.77
OBSVNS.	31	3	27	0	29	28
MAXIMUM	66.2	28.85	62.6	0.00	60.8	31.08
MINIMUM	55.4	27.54	55.4	0.00	51.8	26.45
STD.DEV.	3.63	.715	2.30	0.000	2.92	1.200

BAMFIELD 48 50 05 N 125 08 07 W

	OCTOBER			NOVEMBER			DECEMBER 1972		
DATE	TEMP		SAL	TEMP		SAL	TEMP		SAL
1	53.6		28.09	48.2	*	0.00	48.2	*	0.00
2	53.6		29.29	48.2	*	0.00	46.4	*	0.00
3	53.6		29.60	50.0	*	0.00	46.4	*	0.00
4	51.8		30.42	50.0	*	0.00	46.4	*	0.00
5	51.8	*	0.00	48.2	*	0.00	44.6	*	0.00
6	51.8	*	0.00	48.2	*	0.00	46.4	*	0.00
7	51.8	*	0.00	49.1	*	0.00	45.5		31.10
8	53.6	*	0.00	48.2	*	0.00	44.6		30.73
9	52.7	*	0.00	48.2	*	0.00	43.7		31.00
10	51.8	*	0.00	50.0	*	0.00	42.8		31.08
11	51.8	*	0.00	48.2	*	0.00	43.7		31.29
12	53.6		31.22	48.2	*	0.00	43.7		31.25
13	51.8	*	0.00	48.2	*	0.00	45.5		31.02
14	51.8	*	0.00	48.2	*	0.00	44.6		31.89
15	51.8	*	0.00	48.2	*	0.00	42.8		31.99
16	50.9	*	0.00	48.2	*	0.00	46.4		29.97
17	48.2	*	0.00	46.4	*	0.00	46.4		29.51
18	49.1	*	0.00	48.2	*	0.00	46.4		28.56
19	49.1	*	0.00	47.3	*	0.00	46.4		27.18
20	50.0	*	0.00	48.2	*	0.00	46.4		22.71
21	50.0	*	0.00	48.2	*	0.00	44.6		11.09
22	50.0	*	0.00	48.2	*	0.00	45.5		20.42
23	50.0	*	0.00	49.1	*	0.00	46.4		23.57
24	50.0	*	0.00	48.2	*	0.00	45.5		21.90
25	50.0	*	0.00	48.2	*	0.00	47.3		26.58
26	50.0	*	0.00	48.2	*	0.00	46.4		26.70
27	48.2	*	0.00	46.4	*	0.00	44.6		15.65
28	50.0	*	0.00	48.2	*	0.00	42.8		16.65
29	48.2	*	0.00	47.3	*	0.00	46.4		19.81
30	48.2	*	0.00	48.2	*	0.00	44.6		11.08
31	48.2	*	0.00	0.0		0.00	42.8		20.40
MEANS	50.9		29.72	48.3		0.00	45.3		25.33
OBSVNS.	31		5	30		0	31		25
YRLY.MEANS..........							50.8		
MAXIMUM	53.6		31.22	50.0		0.00	48.2		31.99
MINIMUM	48.2		28.09	46.4		0.00	42.8		11.08
STD.DEV.	1.79		1.183	.82		0.000	1.45		6.614

BAMFIELD 48 50 05 N 125 08 07 W

	JANUARY		FEBRUARY		MARCH	1973
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	46.4	27.82	44.6	28.38	44.6	20.79
2	44.6	27.58	43.7	* 26.89	45.5	25.74
3	44.6	27.81	44.6	25.40	45.5	27.09
4	42.8	25.61	43.7	27.11	46.4	25.35
5	43.7	28.59	43.7	28.23	46.4	26.47
6	43.7	28.82	44.6	29.96	47.3	26.87
7	42.8	29.17	45.5	30.02	47.3	26.41
8	43.7	* 29.83	45.5	30.15	46.4	26.83
9	44.6	30.48	45.5	29.75	47.3	26.14
10	45.5	30.53	45.5	29.98	46.4	27.54
11	44.6	30.10	44.6	29.16	48.2	23.28
12	44.6	29.52	44.6	29.13	46.4	24.69
13	44.6	28.79	44.6	29.73	45.5	25.91
14	45.5	28.55	45.5	30.61	46.4	24.30
15	44.6	26.42	45.5	29.71	46.4	27.03
16	45.5	26.00	45.5	29.42	46.4	27.13
17	43.7	14.29	45.5	29.63	46.4	28.43
18	43.7	23.74	45.5	29.65	45.5	27.66
19	42.8	23.59	46.4	29.90	46.4	27.67
20	44.6	28.84	46.4	29.69	46.4	24.65
21	45.5	28.04	47.3	29.78	46.4	27.93
22	43.7	23.97	47.3	30.36	48.2	25.16
23	45.5	28.83	47.3	29.98	49.1	25.12
24	44.6	24.93	47.3	30.30	49.1	26.32
25	43.7	21.09	47.3	30.22	50.0	23.12
26	43.7	24.03	46.4	30.43	50.0	24.85
27	43.7	27.57	46.4	30.43	48.2	25.54
28	43.7	27.84	45.5	29.28	47.3	25.49
29	44.6	28.54	0.0	0.00	48.2	25.91
30	44.6	27.43	0.0	0.00	48.2	26.58
31	42.8	22.73	0.0	0.00	46.4	27.74
MEANS	44.3	26.71	45.6	29.50	47.0	25.93
OBSVNS.	31	30	28	27	31	31
MAXIMUM	46.4	30.53	47.3	30.61	50.0	28.43
MINIMUM	42.8	14.29	43.7	25.40	44.6	20.79
STD.DEV.	.92	3.372	1.12	1.116	1.34	1.626

BAMFIELD 48 50 05 N 125 08 07 W

	APRIL		MAY		JUNE	1973
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	50.0	27.09	* 0.0	* 0.00
2	* 0.0	* 0.00	50.0	27.35	* 0.0	* 0.00
3	* 0.0	* 0.00	51.8	25.87	* 0.0	* 0.00
4	* 0.0	* 0.00	53.6	25.53	* 0.0	23.03
5	* 0.0	* 0.00	53.6	26.81	53.6	23.07
6	* 0.0	* 0.00	50.0	30.97	53.6	29.17
7	* 0.0	* 0.00	50.0	31.06	53.6	30.12
8	* 0.0	* 0.00	51.8	28.69	57.2	26.89
9	* 0.0	* 0.00	51.8	28.93	57.2	* 26.93
10	* 0.0	* 0.00	51.8	28.99	53.6	* 26.98
11	* 0.0	* 0.00	51.8	28.38	57.2	27.02
12	* 0.0	* 0.00	53.6	28.62	53.6	29.79
13	* 0.0	* 0.00	55.4	30.04	53.6	29.89
14	* 0.0	* 0.00	51.8	30.31	53.6	26.11
15	* 0.0	* 0.00	53.6	29.59	53.6	21.08
16	50.0	29.15	55.4	29.06	* 0.0	* 0.00
17	51.8	29.15	55.4	29.25	* 0.0	* 0.00
18	50.0	30.39	* 0.0	* 0.00	* 0.0	* 0.00
19	51.8	28.76	* 0.0	* 0.00	58.1	20.99
20	51.8	28.43	* 0.0	* 0.00	64.4	25.57
21	51.8	28.64	* 0.0	* 0.00	64.4	23.90
22	51.8	28.67	55.4	25.19	59.0	24.12
23	50.0	29.19	53.6	31.46	57.2	27.18
24	51.8	29.62	53.6	28.85	55.4	27.08
25	51.8	29.13	53.6	23.38	57.2	27.13
26	53.6	25.99	55.4	23.26	59.0	* 0.00
27	48.2	27.05	57.2	23.07	60.8	* 0.00
28	51.8	27.57	55.4	23.10	60.8	* 0.00
29	51.8	27.51	57.2	24.08	55.4	* 0.00
30	52.7	27.23	55.4	24.00	55.4	* 0.00
31	0.0	0.00	* 0.0	27.64	0.0	0.00
MEANS	51.4	28.43	53.4	27.43	56.8	26.01
OBSVNS.	15	15	26	27	23	17
MAXIMUM	53.6	30.39	57.2	31.46	64.4	30.12
MINIMUM	48.2	25.99	50.0	23.07	53.6	20.99
STD.DEV.	1.31	1.148	2.18	2.663	3.35	2.927

BAMFIELD 48 50 05 N 125 08 07 W

	JULY		AUGUST		SEPTEMBER 1973	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
2	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
3	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
4	57.2	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
5	55.4	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
6	55.4	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
7	55.4	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
8	57.2	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
9	59.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
10	59.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
11	60.8	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
12	64.4	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
13	64.4	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
14	66.2	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
15	66.2	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
16	66.2	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
17	66.2	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
18	66.2	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
19	68.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
20	66.2	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
21	59.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
22	60.8	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
23	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
24	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
25	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
26	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
27	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
28	64.4	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
29	60.8	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
30	60.8	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
31	60.8	* 0.00	* 0.0	* 0.00	0.0	0.00
MEANS	61.7	0.00	0.0	0.00	0.0	0.00
OBSVNS.	23	0	0	0	0	0
MAXIMUM	68.0	0.00	0.0	0.00	0.0	0.00
MINIMUM	55.4	0.00	0.0	0.00	0.0	0.00
STD.DEV.	4.09	0.000	0.00	0.000	0.00	0.000

BAMFIELD 48 50 05 N 125 08 07 W

	OCTOBER		NOVEMBER		DECEMBER	1973
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	55.4	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
2	55.4	* 0.00	* 0.0	* 0.00	* 0.0	29.99
3	55.4	* 0.00	* 0.0	* 0.00	46.4	26.49
4	56.3	* 0.00	* 0.0	* 0.00	42.8	27.88
5	55.4	* 0.00	* 0.0	* 0.00	43.7	29.58
6	57.2	* 0.00	* 0.0	* 0.00	* 0.0	28.92
7	55.4	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
8	52.7	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
9	50.9	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
10	50.0	* 0.00	* 0.0	* 0.00	41.0	30.72
11	50.0	* 0.00	* 0.0	* 0.00	41.9	30.50
12	55.4	* 0.00	* 0.0	* 0.00	42.8	28.28
13	55.4	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
14	55.4	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
15	54.5	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
16	* 54.8	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
17	* 55.1	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
18	55.4	* 0.00	* 0.0	* 0.00	44.6	29.67
19	55.4	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
20	53.6	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
21	* 54.5	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
22	55.4	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
23	57.2	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
24	51.8	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
25	55.4	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
26	55.4	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
27	* 55.4	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
28	55.4	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
29	50.9	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
30	53.6	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
31	57.2	* 0.00	0.0	0.00	* 0.0	* 0.00
MEANS	54.5	0.00	0.0	0.00	43.3	29.11
OBSVNS.	27	0	0	0	7	9
YRLY.MEANS................................						
MAXIMUM	57.2	0.00	0.0	0.00	46.4	30.72
MINIMUM	50.0	0.00	0.0	0.00	41.0	26.49
STD.DEV.	2.10	0.000	0.00	0.000	1.79	1.366

BAMFIELD 48 50 05 N 125 08 07 W

	JANUARY				FEBRUARY				MARCH			1974
DATE		TEMP		SAL		TEMP		SAL		TEMP		SAL
1	*	0.0	*	0.00	*	0.0	*	0.00	*	0.0	*	0.00
2		44.6		29.55	*	0.0	*	0.00	*	0.0	*	0.00
3		42.8		28.80	*	0.0	*	0.00	*	0.0	*	0.00
4	*	43.1	*	29.42	*	0.0	*	0.00	*	0.0	*	0.00
5	*	43.4	*	30.05	*	0.0	*	0.00	*	0.0	*	0.00
6		43.7		30.67	*	0.0	*	0.00	*	0.0	*	0.00
7		42.8		29.13	*	0.0	*	0.00	*	0.0	*	0.00
8		43.7		27.79	*	0.0	*	0.00	*	0.0	*	0.00
9		45.5		27.70	*	0.0	*	0.00	*	0.0	*	0.00
10	*	43.4		30.46	*	0.0	*	0.00	*	0.0	*	0.00
11	*	41.3		30.30	*	0.0	*	0.00	*	0.0	*	0.00
12		39.2		29.15	*	0.0	*	0.00	*	0.0	*	0.00
13	*	40.1	*	28.86	*	0.0	*	0.00	*	0.0	*	0.00
14		41.0		28.57	*	0.0	*	0.00	*	0.0	*	0.00
15		42.8		28.75	*	0.0	*	0.00	*	0.0	*	0.00
16	*	43.2		28.68	*	0.0	*	0.00	*	0.0	*	0.00
17		43.7		28.96	*	0.0	*	0.00	*	0.0	*	0.00
18	*	0.0	*	28.93	*	0.0	*	0.00	*	0.0	*	0.00
19	*	0.0	*	28.90	*	0.0	*	0.00	*	0.0	*	0.00
20	*	0.0		28.88	*	0.0	*	0.00	*	0.0	*	0.00
21	*	0.0	*	28.76	*	0.0	*	0.00	*	0.0	*	0.00
22	*	0.0	*	28.65	*	0.0	*	0.00	*	0.0	*	0.00
23		45.5		28.54	*	0.0	*	0.00	*	0.0	*	0.00
24	*	0.0		28.50	*	0.0	*	0.00	*	0.0	*	0.00
25	*	0.0	*	0.00	*	0.0	*	0.00	*	0.0	*	0.00
26	*	0.0	*	0.00	*	0.0	*	0.00	*	0.0	*	0.00
27	*	0.0	*	0.00	*	0.0	*	0.00	*	0.0	*	0.00
28	*	0.0	*	0.00	*	0.0	*	0.00	*	0.0	*	0.00
29	*	0.0	*	0.00		0.0		0.00	*	0.0	*	0.00
30	*	0.0	*	0.00		0.0		0.00	*	0.0	*	0.00
31	*	0.0	*	0.00		0.0		0.00	*	0.0	*	0.00
MEANS		43.2		29.03		0.0		0.00		0.0		0.00
OBSVNS.		11		16		0		0		0		0
MAXIMUM		45.5		30.67		0.0		0.00		0.0		0.00
MINIMUM		39.2		27.70		0.0		0.00		0.0		0.00
STD.DEV.		1.86		.855		0.00		0.000		0.00		0.000

BAMFIELD 48 50 05 N 125 08 07 W

	APRIL		MAY		JUNE	1974
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
2	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
3	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
4	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
5	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
6	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
7	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
8	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
9	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
10	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
11	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
12	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
13	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
14	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
15	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
16	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
17	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
18	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
19	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
20	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
21	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
22	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
23	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
24	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
25	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
26	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
27	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
28	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
29	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
30	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
31	0.0	0.00	* 0.0	* 0.00	0.0	0.00
MEANS	0.0	0.00	0.0	0.00	0.0	0.00
OBSVNS.	0	0	0	0	0	0
MAXIMUM	0.0	0.00	0.0	0.00	0.0	0.00
MINIMUM	0.0	0.00	0.0	0.00	0.0	0.00
STD.DEV.	0.00	0.000	0.00	0.000	0.00	0.000

BAMFIELD 48 50 05 N 125 08 07 W

	JULY		AUGUST		SEPTEMBER 1974	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
2	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
3	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
4	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
5	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
6	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
7	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
8	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
9	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
10	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
11	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
12	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
13	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
14	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
15	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
16	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
17	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
18	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
19	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
20	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
21	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
22	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
23	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
24	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
25	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
26	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
27	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
28	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
29	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
30	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
31	* 0.0	* 0.00	* 0.0	* 0.00	0.0	0.00
MEANS	0.0	0.00	0.0	0.00	0.0	0.00
OBSVNS.	0	0	0	0	0	0
MAXIMUM	0.0	0.00	0.0	0.00	0.0	0.00
MINIMUM	0.0	0.00	0.0	0.00	0.0	0.00
STD.DEV.	0.00	0.000	0.00	0.000	0.00	0.000

BAMFIELD 48 50 05 N 125 08 07 W

	OCTOBER		NOVEMBER		DECEMBER	1974
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
2	* 0.0	* 0.00	* 0.0	* 0.00	44.6	* 0.00
3	* 0.0	* 0.00	* 0.0	* 0.00	46.4	* 0.00
4	* 0.0	* 0.00	46.4	* 0.00	42.8	* 0.00
5	* 0.0	* 0.00	44.6	* 0.00	43.7	* 0.00
6	* 0.0	* 0.00	46.4	* 0.00	44.6	* 0.00
7	* 0.0	* 0.00	47.3	* 0.00	* 43.4	* 0.00
8	* 0.0	* 0.00	47.3	* 0.00	* 42.2	* 0.00
9	* 0.0	* 0.00	* 0.0	* 0.00	41.0	* 0.00
10	* 0.0	* 0.00	* 0.0	* 0.00	41.0	* 0.00
11	* 0.0	* 0.00	* 0.0	* 0.00	41.9	* 0.00
12	* 0.0	* 0.00	44.6	* 0.00	42.8	* 0.00
13	* 0.0	* 0.00	44.6	* 0.00	46.4	* 0.00
14	* 0.0	* 0.00	47.3	* 0.00	* 0.0	* 0.00
15	46.4	* 0.00	46.4	* 0.00	* 0.0	* 0.00
16	47.3	* 0.00	47.3	* 0.00	* 0.0	* 0.00
17	47.3	* 0.00	* 47.6	* 0.00	42.8	* 0.00
18	47.3	* 0.00	* 47.9	* 0.00	44.6	* 0.00
19	* 47.0	* 0.00	48.2	* 0.00	44.6	* 0.00
20	* 46.7	* 0.00	47.3	* 0.00	39.2	* 0.00
21	46.4	* 0.00	46.4	* 0.00	* 40.1	* 0.00
22	47.3	* 0.00	47.3	* 0.00	* 41.0	* 0.00
23	47.3	* 0.00	* 47.3	* 0.00	41.9	* 0.00
24	48.2	* 0.00	* 47.3	* 0.00	* 0.0	* 0.00
25	46.4	* 0.00	47.3	* 0.00	* 0.0	* 0.00
26	* 46.7	* 0.00	44.6	* 0.00	* 0.0	* 0.00
27	* 47.0	* 0.00	46.4	* 0.00	* 0.0	* 0.00
28	47.3	* 0.00	45.5	* 0.00	* 0.0	* 0.00
29	46.4	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
30	46.4	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
31	45.5	* 0.00	0.0	0.00	* 0.0	* 0.00
MEANS	46.9	0.00	46.4	0.00	43.2	0.00
OBSVNS.	13	0	18	0	15	0
YRLY.MEANS..						
MAXIMUM	48.2	0.00	48.2	0.00	46.4	0.00
MINIMUM	45.5	0.00	44.6	0.00	39.2	0.00
STD.DEV.	.70	0.000	1.16	0.000	2.04	0.000

BAMFIELD 48 50 05 N 125 08 07 W

	JANUARY		FEBRUARY		MARCH	1975
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	* 0.0	* 0.00	42.8	* 0.00
2	44.6	* 0.00	* 0.0	* 0.00	41.9	* 0.00
3	42.8	* 0.00	* 0.0	* 0.00	39.2	* 0.00
4	* 43.1	* 0.00	* 0.0	* 0.00	42.8	* 0.00
5	* 43.4	* 0.00	* 0.0	* 0.00	40.1	* 0.00
6	43.7	* 0.00	* 0.0	* 0.00	44.6	* 0.00
7	42.8	* 0.00	44.6	* 0.00	44.6	* 0.00
8	43.7	* 0.00	42.8	* 0.00	42.8	* 0.00
9	45.5	* 0.00	42.8	* 0.00	44.6	* 0.00
10	45.5	* 0.00	41.0	* 0.00	41.9	* 0.00
11	39.2	* 0.00	44.6	* 0.00	42.8	* 0.00
12	39.2	* 0.00	44.6	* 0.00	41.9	* 0.00
13	39.2	* 0.00	44.6	* 0.00	42.8	* 0.00
14	41.0	* 0.00	44.6	* 0.00	42.8	* 0.00
15	42.8	* 0.00	44.6	* 0.00	40.1	* 0.00
16	44.6	* 0.00	44.6	* 0.00	42.8	* 0.00
17	43.7	* 0.00	44.6	* 0.00	42.8	* 0.00
18	41.0	* 0.00	44.6	* 0.00	42.8	* 0.00
19	39.2	* 0.00	44.6	* 0.00	43.7	* 0.00
20	44.6	* 0.00	42.8	* 0.00	43.7	* 0.00
21	41.0	* 0.00	42.8	* 0.00	44.6	* 0.00
22	42.8	* 0.00	43.7	* 0.00	43.7	* 0.00
23	45.5	* 0.00	42.8	* 0.00	* 0.0	* 0.00
24	44.6	* 0.00	42.8	* 0.00	* 0.0	* 0.00
25	* 44.3	* 0.00	42.8	* 0.00	* 0.0	* 0.00
26	* 44.0	* 0.00	44.6	* 0.00	44.6	* 0.00
27	43.7	* 0.00	42.8	* 0.00	42.8	* 0.00
28	43.7	* 0.00	46.4	* 0.00	46.4	* 0.00
29	40.1	* 0.00	0.0	0.00	46.4	* 0.00
30	46.4	* 0.00	0.0	0.00	45.5	* 0.00
31	44.6	* 0.00	0.0	0.00	44.6	* 0.00
MEANS	42.9	0.00	43.8	0.00	43.2	0.00
OBSVNS.	26	0	22	0	28	0
MAXIMUM	46.4	0.00	46.4	0.00	46.4	0.00
MINIMUM	39.2	0.00	41.0	0.00	39.2	0.00
STD.DEV.	2.22	0.000	1.19	0.000	1.72	0.000

BAMFIELD 48 50 05 N 125 08 07 W

	APRIL		MAY		JUNE	1975
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	54.5	29.33	* 0.0	* 0.00
2	* 0.0	* 0.00	50.0	31.88	* 0.0	* 0.00
3	* 0.0	* 0.00	48.2	31.54	* 0.0	* 0.00
4	* 0.0	* 0.00	51.8	27.07	* 0.0	* 0.00
5	* 0.0	* 0.00	* 51.8	* 28.07	* 0.0	* 0.00
6	* 0.0	* 0.00	* 51.8	* 29.08	* 0.0	* 0.00
7	* 0.0	* 0.00	51.8	30.08	* 0.0	* 0.00
8	* 0.0	* 0.00	* 51.5	* 30.13	60.8	23.57
9	* 0.0	* 0.00	* 51.2	* 30.18	55.4	30.74
10	* 0.0	* 0.00	50.9	30.23	* 0.0	* 0.00
11	* 0.0	* 0.00	51.8	31.06	* 0.0	* 0.00
12	* 0.0	* 0.00	52.7	31.16	* 0.0	* 0.00
13	* 0.0	* 0.00	54.5	29.13	* 0.0	* 0.00
14	* 0.0	* 0.00	51.8	30.83	57.2	28.34
15	* 0.0	* 0.00	50.0	31.47	* 57.8	29.73
16	* 0.0	* 0.00	* 0.0	* 0.00	58.5	29.77
17	* 0.0	* 0.00	* 0.0	* 0.00	62.6	23.42
18	* 0.0	* 0.00	* 0.0	* 0.00	60.8	26.37
19	* 0.0	* 0.00	* 0.0	* 0.00	58.1	28.09
20	* 0.0	* 0.00	* 0.0	* 0.00	* 58.4	* 27.95
21	* 0.0	* 0.00	51.8	21.66	* 58.7	* 27.80
22	* 0.0	* 0.00	* 52.4	* 24.73	59.0	27.66
23	* 0.0	* 0.00	* 53.0	* 27.80	61.7	23.21
24	* 0.0	* 0.00	53.6	30.87	64.4	29.46
25	* 0.0	* 0.00	53.6	30.33	* 62.6	* 28.87
26	* 0.0	* 0.00	* 0.0	* 0.00	* 60.8	* 28.28
27	* 0.0	* 0.00	* 0.0	* 0.00	59.0	27.68
28	* 0.0	* 0.00	* 0.0	* 0.00	* 60.3	* 27.54
29	* 0.0	* 0.00	57.2	27.03	61.7	27.39
30	* 0.0	* 0.00	* 60.3	* 26.86	64.4	27.86
31	0.0	0.00	63.5	26.69	0.0	0.00
MEANS	0.0	0.00	53.0	29.40	60.3	27.38
OBSVNS.	0	0	16	16	13	14
MAXIMUM	0.0	0.00	63.5	31.88	64.4	30.74
MINIMUM	0.0	0.00	48.2	21.66	55.4	23.21
STD.DEV.	0.00	0.000	3.52	2.652	2.71	2.438

BAMFIELD 48 50 05 N 125 08 07 W

	JULY		AUGUST		SEPTEMBER 1975	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	57.2	30.41	* 0.0	32.89	* 0.0	* 0.00
2	60.3	30.29	* 0.0	32.86	* 0.0	* 0.00
3	63.5	28.14	* 0.0	* 31.77	* 0.0	* 0.00
4	60.8	28.75	60.8	30.68	* 0.0	* 0.00
5	61.7	29.64	59.0	* 31.45	* 0.0	* 0.00
6	61.7	29.65	60.8	32.22	* 0.0	* 0.00
7	59.0	27.73	59.0	32.21	* 0.0	* 0.00
8	* 60.3	31.02	* 0.0	* 0.00	* 0.0	* 0.00
9	61.7	30.78	* 0.0	* 0.00	* 0.0	* 0.00
10	* 61.7	* 31.62	* 0.0	* 0.00	* 0.0	* 0.00
11	61.7	32.46	60.8	32.06	* 0.0	* 0.00
12	61.7	32.50	64.4	31.93	* 0.0	* 0.00
13	60.8	32.96	* 63.5	* 31.05	* 0.0	* 0.00
14	62.6	28.93	62.6	30.16	* 0.0	* 0.00
15	* 62.0	* 29.70	* 0.0	* 0.00	* 0.0	* 0.00
16	* 61.4	* 30.47	* 0.0	* 0.00	* 0.0	* 0.00
17	60.8	31.25	* 0.0	* 0.00	* 0.0	* 0.00
18	60.8	28.52	60.8	30.70	* 0.0	* 0.00
19	59.0	29.57	59.9	32.57	* 0.0	* 0.00
20	59.9	* 29.99	* 0.0	32.75	* 0.0	* 0.00
21	60.8	30.41	* 0.0	32.64	* 0.0	* 0.00
22	64.4	29.66	* 0.0	* 0.00	* 0.0	* 0.00
23	64.4	31.14	* 0.0	* 0.00	* 0.0	* 0.00
24	* 64.4	* 30.51	60.8	* 0.00	* 0.0	* 0.00
25	64.4	29.87	56.3	* 0.00	* 0.0	* 0.00
26	* 59.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
27	53.6	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
28	59.9	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
29	63.5	32.67	* 0.0	* 0.00	* 0.0	* 0.00
30	64.4	32.92	* 0.0	* 0.00	* 0.0	* 0.00
31	* 0.0	* 32.91	* 0.0	* 0.00	0.0	0.00
MEANS	61.2	30.42	60.5	31.97	0.0	0.00
OBSVNS.	24	22	11	12	0	0
MAXIMUM	64.4	32.96	64.4	32.89	0.0	0.00
MINIMUM	53.6	27.73	56.3	30.16	0.0	0.00
STD.DEV.	2.50	1.571	2.06	.941	0.00	0.000

BAMFIELD 48 50 05 N 125 08 07 W

	OCTOBER		NOVEMBER		DECEMBER	1975
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	* 0.0	* 0.00	50.4	30.02
2	* 0.0	* 0.00	* 0.0	* 0.00	49.1	30.03
3	* 0.0	* 0.00	* 0.0	* 0.00	50.0	31.12
4	* 0.0	* 0.00	* 0.0	* 0.00	47.8	28.64
5	* 0.0	* 0.00	* 0.0	* 0.00	46.4	25.00
6	* 0.0	* 0.00	* 0.0	* 0.00	47.3	25.02
7	* 0.0	* 0.00	* 0.0	* 0.00	46.9	25.02
8	* 0.0	* 0.00	* 0.0	* 0.00	48.2	25.04
9	* 0.0	* 0.00	* 0.0	* 0.00	48.0	* 23.04
10	* 0.0	* 0.00	* 0.0	* 0.00	47.3	21.05
11	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
12	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
13	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
14	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
15	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
16	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
17	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
18	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
19	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
20	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
21	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
22	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
23	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
24	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
25	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
26	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
27	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
28	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
29	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
30	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
31	* 0.0	* 0.00	0.0	0.00	* 0.0	* 0.00
MEANS	0.0	0.00	0.0	0.00	48.1	26.77
OBSVNS.	0	0	0	0	10	9
YRLY.MEANS..						
MAXIMUM	0.0	0.00	0.0	0.00	50.4	31.12
MINIMUM	0.0	0.00	0.0	0.00	46.4	21.05
STD.DEV.	0.00	0.000	0.00	0.000	1.32	3.328

BAMFIELD 48 50 05 N 125 08 07 W

	JANUARY		FEBRUARY		MARCH	1976
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
2	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
3	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
4	* 0.0	* 0.00	44.6	30.04	* 0.0	* 0.00
5	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
6	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
7	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
8	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
9	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
10	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
11	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
12	* 0.0	* 0.00	46.4	28.96	* 0.0	* 0.00
13	* 0.0	* 0.00	44.6	28.99	* 0.0	* 0.00
14	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
15	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
16	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
17	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
18	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
19	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
20	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
21	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
22	46.4	27.29	* 0.0	* 0.00	* 0.0	* 0.00
23	44.6	28.68	* 0.0	* 0.00	* 0.0	* 0.00
24	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
25	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
26	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
27	46.4	30.03	* 0.0	* 0.00	* 0.0	* 0.00
28	48.2	30.03	* 0.0	* 0.00	* 0.0	* 0.00
29	46.4	29.53	* 0.0	* 0.00	* 0.0	* 0.00
30	* 0.0	* 0.00	0.0	0.00	* 0.0	* 0.00
31	* 0.0	* 0.00	0.0	0.00	* 0.0	* 0.00
MEANS	46.4	29.11	45.2	29.33	0.0	0.00
OBSVNS.	5	5	3	3	0	0
MAXIMUM	48.2	30.03	46.4	30.04	0.0	0.00
MINIMUM	44.6	27.29	44.6	28.96	0.0	0.00
STD.DEV.	1.27	1.158	1.04	.615	0.00	0.000

BAMFIELD 48 50 05 N 125 08 07 W

	APRIL		MAY		JUNE	1976
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	* 0.0	* 0.00	* 54.7	* 25.27
2	* 0.0	* 0.00	* 0.0	* 0.00	57.0	22.05
3	* 0.0	* 0.00	* 0.0	* 0.00	56.8	25.42
4	* 0.0	* 0.00	* 0.0	* 0.00	* 58.1	* 23.62
5	* 0.0	* 0.00	* 0.0	* 0.00	59.4	21.82
6	* 0.0	* 0.00	* 0.0	* 0.00	59.4	24.82
7	* 0.0	* 0.00	* 0.0	* 0.00	57.6	26.93
8	* 0.0	* 0.00	* 0.0	* 0.00	57.6	26.30
9	* 0.0	* 0.00	53.2	30.18	57.9	26.33
10	* 0.0	* 0.00	53.2	29.74	* 57.5	* 25.29
11	* 0.0	* 0.00	51.8	31.68	57.0	24.25
12	* 0.0	* 0.00	* 52.9	* 27.98	53.2	* 23.17
13	* 0.0	* 0.00	54.0	24.28	* 55.4	* 22.09
14	* 0.0	* 0.00	* 0.0	* 0.00	57.6	21.00
15	* 0.0	* 0.00	* 0.0	* 0.00	* 57.4	* 22.61
16	* 0.0	* 0.00	* 0.0	* 0.00	57.2	24.22
17	* 0.0	* 0.00	53.6	30.16	61.2	23.24
18	* 0.0	* 0.00	55.8	25.27	59.4	29.98
19	* 0.0	* 0.00	* 0.0	* 0.00	57.6	27.68
20	* 0.0	* 0.00	* 0.0	* 0.00	* 57.6	* 27.27
21	* 0.0	* 0.00	* 0.0	* 0.00	* 57.6	* 26.87
22	* 0.0	* 0.00	* 0.0	* 0.00	57.6	26.46
23	* 0.0	* 0.00	* 0.0	* 0.00	58.6	26.24
24	* 0.0	* 0.00	52.5	23.59	58.6	25.52
25	* 0.0	* 0.00	52.9	30.47	56.8	28.99
26	* 0.0	* 0.00	51.4	31.08	* 57.5	* 27.21
27	* 0.0	* 0.00	52.0	28.42	* 58.2	* 25.44
28	* 0.0	* 0.00	51.8	29.46	59.0	23.67
29	* 0.0	* 0.00	50.4	30.00	56.8	30.51
30	* 0.0	* 0.00	50.0	31.70	55.8	29.66
31	0.0	0.00	* 52.3	* 28.48	0.0	0.00
MEANS	0.0	0.00	52.5	28.93	57.7	25.75
OBSVNS.	0	0	13	13	21	20
MAXIMUM	0.0	0.00	55.8	31.70	61.2	30.51
MINIMUM	0.0	0.00	50.0	23.59	53.2	21.00
STD.DEV.	0.00	0.000	1.54	2.757	1.61	2.722

BAMFIELD 48 50 05 N 125 08 07 W

	JULY		AUGUST		SEPTEMBER 1976	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	57.6	26.89	* 0.0	* 0.00	59.0	26.70
2	55.6	26.07	* 0.0	* 0.00	* 0.0	* 0.00
3	60.1	23.77	* 0.0	* 0.00	* 0.0	* 0.00
4	* 59.1	* 24.13	* 0.0	* 0.00	* 0.0	* 0.00
5	58.1	24.48	* 0.0	* 0.00	* 0.0	* 0.00
6	56.8	23.65	* 0.0	* 0.00	* 0.0	* 0.00
7	59.2	26.24	* 0.0	* 0.00	* 0.0	* 0.00
8	60.3	27.57	* 0.0	* 0.00	* 0.0	* 0.00
9	* 0.0	* 0.00	59.9	26.03	* 0.0	* 0.00
10	* 0.0	* 0.00	59.4	27.14	* 0.0	* 0.00
11	* 0.0	* 0.00	60.8	27.16	* 0.0	* 0.00
12	* 0.0	* 0.00	60.3	27.05	* 0.0	* 0.00
13	61.2	26.44	* 59.7	27.90	* 0.0	* 0.00
14	62.1	25.39	* 59.1	* 0.00	* 0.0	* 0.00
15	63.7	24.05	58.5	* 0.00	* 0.0	* 0.00
16	62.6	25.63	58.1	* 0.00	* 0.0	* 0.00
17	61.2	27.46	* 0.0	* 0.00	* 0.0	* 0.00
18	* 60.4	* 27.02	* 0.0	20.02	* 0.0	* 0.00
19	* 59.7	* 26.57	* 0.0	* 0.00	* 0.0	* 0.00
20	59.0	26.12	* 0.0	* 0.00	* 0.0	* 0.00
21	58.5	26.77	* 0.0	* 0.00	* 0.0	* 0.00
22	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
23	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
24	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
25	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
26	* 0.0	* 0.00	56.3	29.33	* 0.0	* 0.00
27	* 0.0	* 0.00	54.3	28.86	* 0.0	* 0.00
28	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
29	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
30	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
31	* 0.0	* 0.00	59.0	26.32	0.0	0.00
MEANS	59.7	25.75	58.5	26.65	59.0	26.70
OBSVNS.	14	14	9	9	1	1
MAXIMUM	63.7	27.57	60.8	29.33	59.0	26.70
MINIMUM	55.6	23.65	54.3	20.02	59.0	26.70
STD.DEV.	2.31	1.316	2.07	2.710	I	I

BAMFIELD 48 50 05 N 125 08 07 W

	OCTOBER		NOVEMBER		DECEMBER 1976	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	* 0.0	30.24	* 0.0	* 31.33
2	* 0.0	* 0.00	* 0.0	31.10	* 0.0	31.28
3	* 0.0	* 0.00	* 0.0	31.70	* 0.0	31.24
4	* 0.0	* 0.00	* 0.0	31.08	* 0.0	31.06
5	* 0.0	* 0.00	* 0.0	30.17	* 0.0	31.18
6	* 0.0	* 0.00	* 0.0	30.55	* 0.0	* 0.00
7	* 0.0	* 0.00	* 0.0	* 30.89	* 0.0	* 0.00
8	* 0.0	* 0.00	* 0.0	31.23	* 0.0	* 0.00
9	* 0.0	* 0.00	* 0.0	31.17	* 0.0	* 0.00
10	* 0.0	* 0.00	* 0.0	31.35	* 0.0	* 0.00
11	* 0.0	* 0.00	* 0.0	31.37	* 0.0	* 0.00
12	* 0.0	* 0.00	* 0.0	* 31.42	* 0.0	* 0.00
13	* 0.0	* 0.00	* 0.0	31.47	* 0.0	* 0.00
14	* 0.0	* 0.00	* 0.0	31.11	* 0.0	* 0.00
15	* 0.0	* 0.00	* 0.0	31.00	* 0.0	* 0.00
16	* 0.0	* 0.00	* 0.0	28.32	* 0.0	* 0.00
17	* 0.0	* 0.00	* 0.0	* 29.81	* 0.0	* 0.00
18	* 0.0	* 0.00	* 0.0	31.29	* 0.0	* 0.00
19	* 0.0	* 0.00	* 0.0	31.38	* 0.0	* 0.00
20	* 0.0	* 0.00	* 0.0	31.15	* 0.0	* 0.00
21	* 0.0	* 0.00	* 0.0	30.92	* 0.0	* 0.00
22	* 0.0	* 0.00	* 0.0	30.68	* 0.0	* 0.00
23	* 0.0	* 0.00	* 0.0	30.81	* 0.0	* 0.00
24	* 0.0	* 0.00	* 0.0	30.34	* 0.0	* 0.00
25	* 0.0	* 0.00	* 0.0	30.47	* 0.0	* 0.00
26	* 0.0	* 0.00	* 0.0	31.12	* 0.0	* 0.00
27	* 0.0	* 0.00	* 0.0	31.23	* 0.0	* 0.00
28	* 0.0	* 0.00	* 0.0	31.33	* 0.0	* 0.00
29	* 0.0	* 0.00	* 0.0	31.27	* 0.0	* 0.00
30	* 0.0	* 0.00	* 0.0	31.37	* 0.0	* 0.00
31	* 0.0	27.98	0.0	0.00	* 0.0	* 0.00
MEANS	0.0	27.98	0.0	30.93	0.0	31.19
OBSVNS.	0	1	0	27	0	4
YRLY.MEANS...						
MAXIMUM	0.0	27.98	0.0	31.70	0.0	31.28
MINIMUM	0.0	27.98	0.0	28.32	0.0	31.06
STD.DEV.	0.00	I	0.00	.654	0.00	.096

BAMFIELD 48 50 05 N 125 08 07 W

	JANUARY		FEBRUARY		MARCH	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
2	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
3	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
4	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
5	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
6	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
7	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
8	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
9	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
10	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
11	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
12	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
13	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
14	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
15	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
16	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
17	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
18	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
19	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
20	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
21	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
22	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
23	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
24	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
25	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
26	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
27	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
28	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
29	* 0.0	* 0.00	0.0	0.00	* 0.0	* 0.00
30	* 0.0	* 0.00	0.0	0.00	* 0.0	* 0.00
31	* 0.0	* 0.00	0.0	0.00	* 0.0	* 0.00
MEANS	0.0	0.00	0.0	0.00	0.0	0.00
OBSVNS.	0	0	0	0	0	0
MAXIMUM	0.0	0.00	0.0	0.00	0.0	0.00
MINIMUM	0.0	0.00	0.0	0.00	0.0	0.00
STD.DEV.	0.00	0.000	0.00	0.000	0.00	0.000

BAMFIELD 48 50 05 N 125 08 07 W

	APRIL		MAY		JUNE	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	* 0.0	* 0.00	* 54.0	* 30.62
2	* 0.0	* 0.00	* 0.0	* 0.00	55.4	30.21
3	* 0.0	* 0.00	* 0.0	* 0.00	55.0	29.29
4	* 0.0	* 0.00	* 0.0	* 0.00	* 56.8	* 28.07
5	* 0.0	* 0.00	* 0.0	* 0.00	* 58.6	* 26.84
6	* 0.0	* 0.00	* 0.0	* 0.00	60.4	25.61
7	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
8	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
9	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
10	* 0.0	* 0.00	* 0.0	* 0.00	59.2	24.75
11	* 0.0	* 0.00	56.7	28.20	* 0.0	* 0.00
12	* 0.0	* 0.00	54.5	27.76	* 0.0	* 0.00
13	* 0.0	* 0.00	55.4	27.56	* 0.0	* 0.00
14	* 0.0	* 0.00	54.9	28.38	59.9	26.20
15	* 0.0	* 0.00	54.0	28.55	59.9	25.12
16	* 0.0	* 0.00	56.3	27.03	60.4	25.97
17	* 0.0	* 0.00	55.8	28.28	59.0	24.65
18	* 0.0	* 0.00	58.1	23.60	* 59.0	* 25.44
19	* 0.0	* 0.00	57.6	25.09	* 59.1	* 26.22
20	* 0.0	* 0.00	56.3	26.42	59.2	27.00
21	* 0.0	* 0.00	* 56.0	* 27.17	* 60.0	* 26.73
22	* 0.0	* 0.00	* 55.7	* 27.92	60.8	26.46
23	* 0.0	* 0.00	55.4	28.67	* 0.0	* 0.00
24	* 0.0	* 0.00	* 55.0	* 29.14	* 0.0	* 0.00
25	* 0.0	* 0.00	54.5	29.62	* 0.0	* 0.00
26	* 0.0	* 0.00	* 53.0	* 29.50	* 0.0	* 0.00
27	* 0.0	* 0.00	51.4	29.38	57.6	26.55
28	* 0.0	* 0.00	* 52.0	* 29.09	* 57.2	* 28.17
29	* 0.0	* 0.00	* 52.6	* 28.81	56.8	29.80
30	* 0.0	* 0.00	53.2	28.52	* 0.0	* 0.00
31	0.0	0.00	52.7	31.03	0.0	0.00
MEANS	0.0	0.00	55.1	27.87	58.6	26.80
OBSVNS.	0	0	15	15	12	12
MAXIMUM	0.0	0.00	58.1	31.03	60.8	30.21
MINIMUM	0.0	0.00	51.4	23.60	55.0	24.65
STD.DEV.	0.00	0.000	1.82	1.818	1.98	1.934

BAMFIELD 48 50 05 N 125 08 07 W

DATE	JULY TEMP	JULY SAL	AUGUST TEMP	AUGUST SAL	SEPTEMBER 1977 TEMP	SEPTEMBER 1977 SAL
1	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
2	* 0.0	* 0.00	63.1	30.14	* 0.0	* 0.00
3	* 0.0	* 0.00	* 64.2	* 29.94	* 0.0	* 0.00
4	55.8	27.80	65.3	29.73	* 0.0	* 0.00
5	* 0.0	* 0.00	64.4	29.26	* 0.0	* 0.00
6	* 0.0	* 0.00	* 64.1	* 29.48	* 0.0	* 0.00
7	* 0.0	* 0.00	* 63.8	* 29.69	* 0.0	* 0.00
8	* 0.0	* 0.00	63.5	29.91	* 0.0	* 0.00
9	* 0.0	* 0.00	62.6	29.41	* 0.0	* 0.00
10	* 0.0	* 0.00	65.1	28.83	* 0.0	* 0.00
11	* 0.0	* 0.00	63.5	29.31	* 0.0	* 0.00
12	57.6	29.91	64.4	29.67	* 0.0	* 0.00
13	* 59.0	* 28.92	* 62.0	* 30.25	* 0.0	* 0.00
14	60.4	27.92	* 59.6	* 30.83	* 0.0	* 0.00
15	59.0	29.38	57.2	31.42	* 0.0	* 0.00
16	* 59.3	* 29.65	* 0.0	* 0.00	* 0.0	* 0.00
17	* 59.6	* 29.92	* 0.0	* 0.00	* 0.0	* 0.00
18	59.9	30.18	* 0.0	* 0.00	* 0.0	* 0.00
19	59.0	28.09	* 0.0	* 0.00	* 0.0	* 0.00
20	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
21	* 0.0	* 0.00	* 0.0	* 0.00	* 0.0	* 0.00
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MEANS	58.5	29.26	63.2	29.74	0.0	0.00
OBSVNS.	7	7	9	9	0	0
MAXIMUM	60.4	31.56	65.3	31.42	0.0	0.00
MINIMUM	55.8	27.80	57.2	28.83	0.0	0.00
STD.DEV.	1.54	1.406	2.44	.739	0.00	0.000

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Annual Graphs of the 7-day

Normally-Weighted Running Means

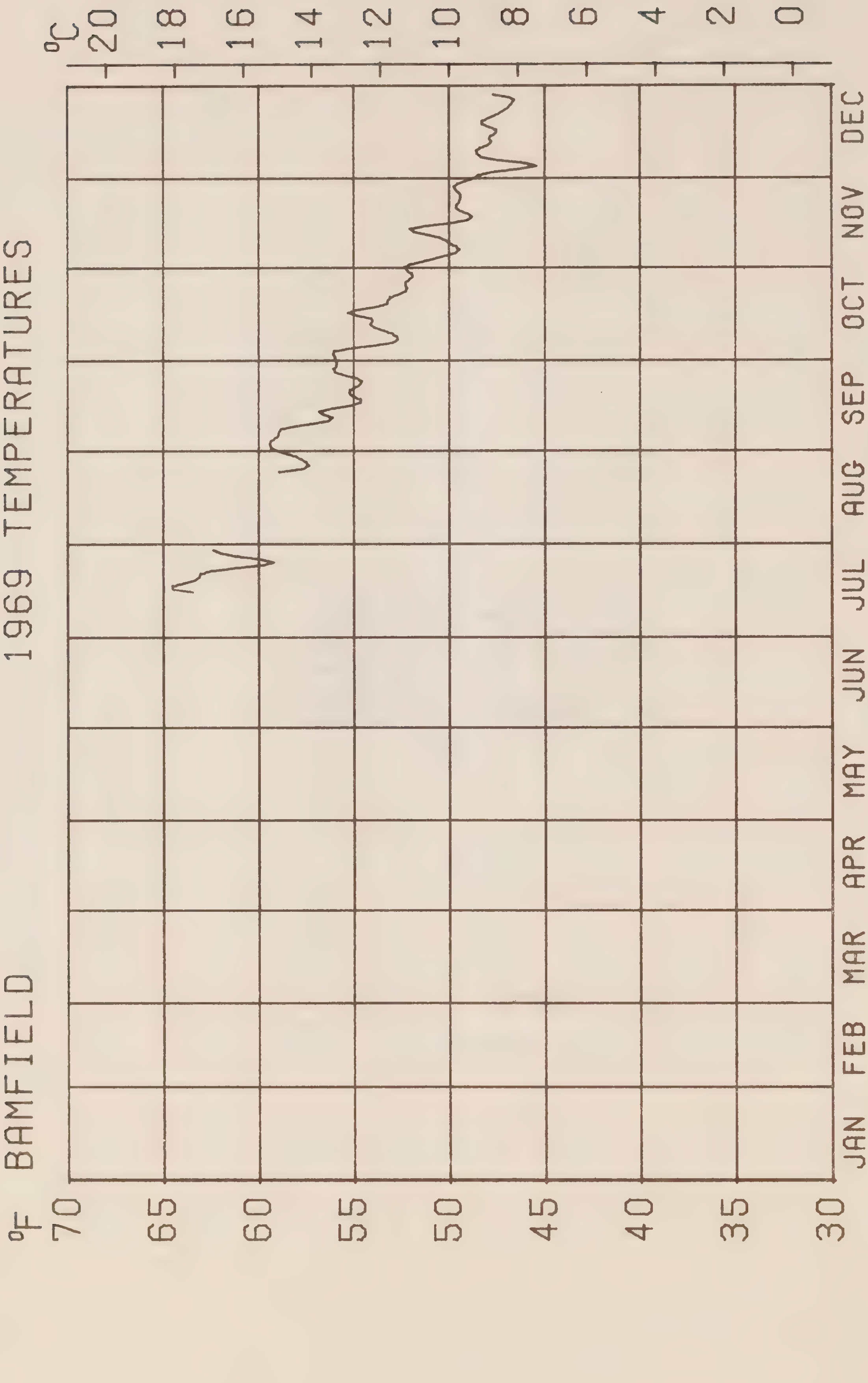
for Temperature and Salinity

1969-1977

BAMFIELD

TEMP: Temperature (^{o}C and ^{o}F)

SAL: Salinity (^{o}/oo)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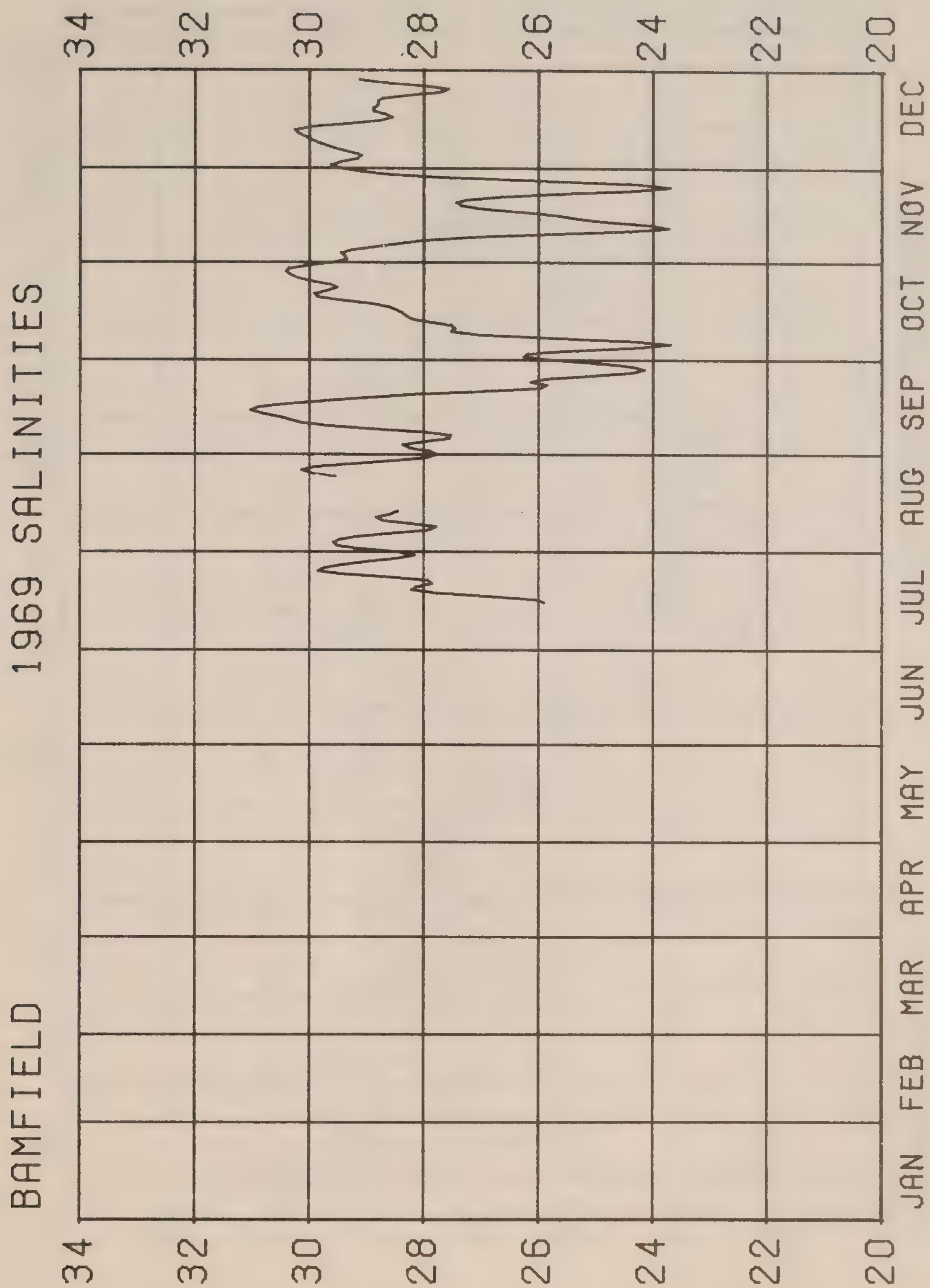
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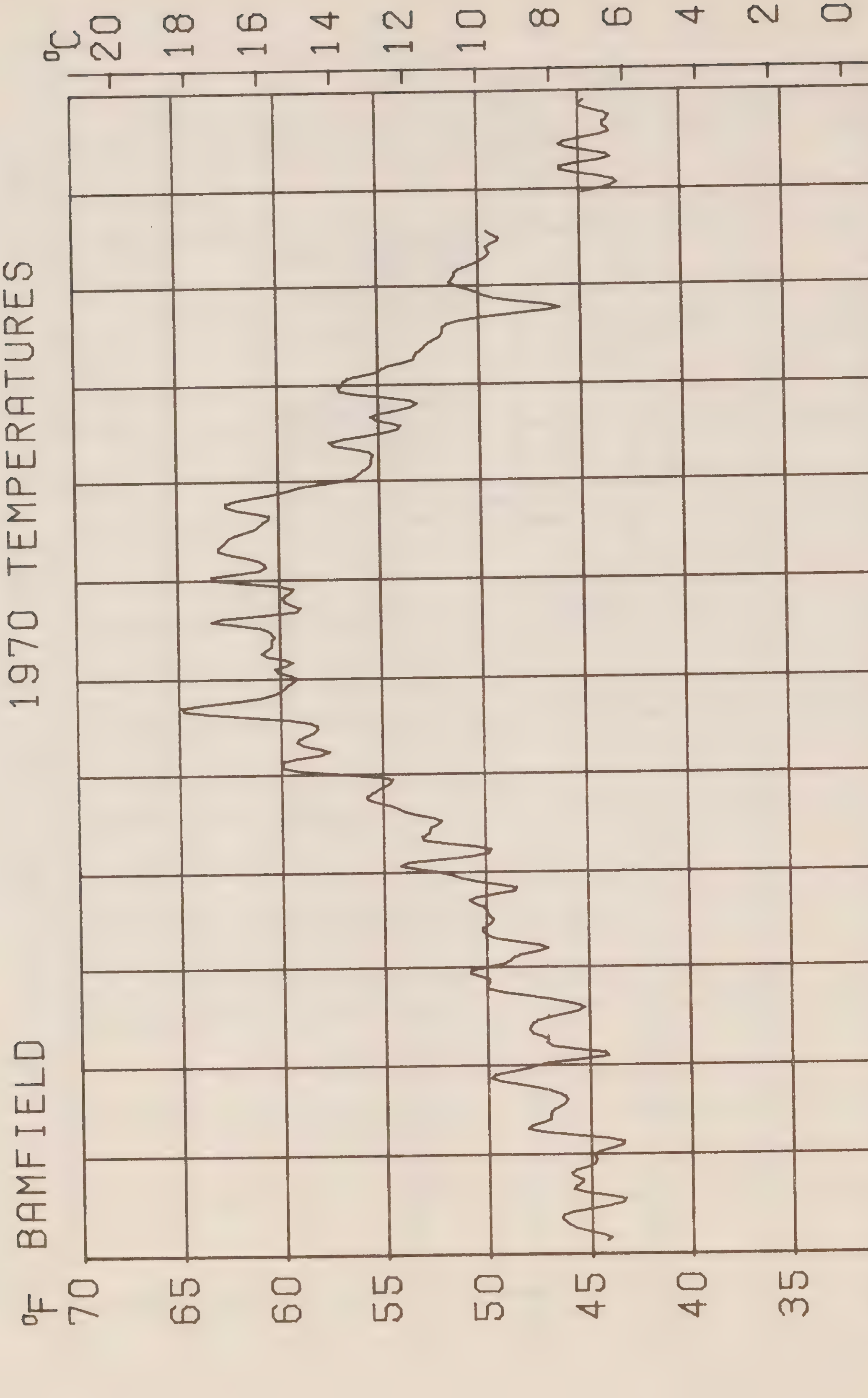
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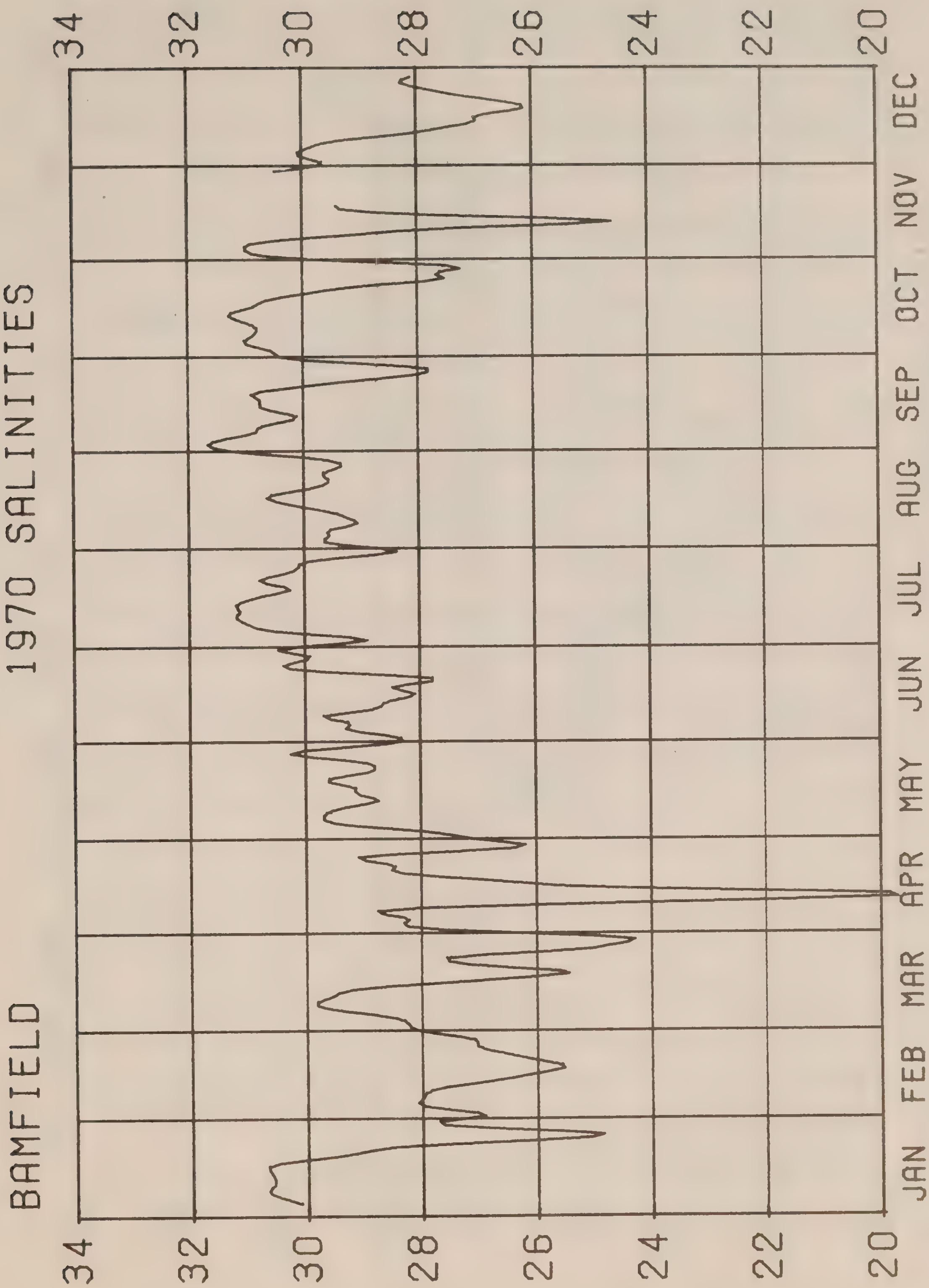
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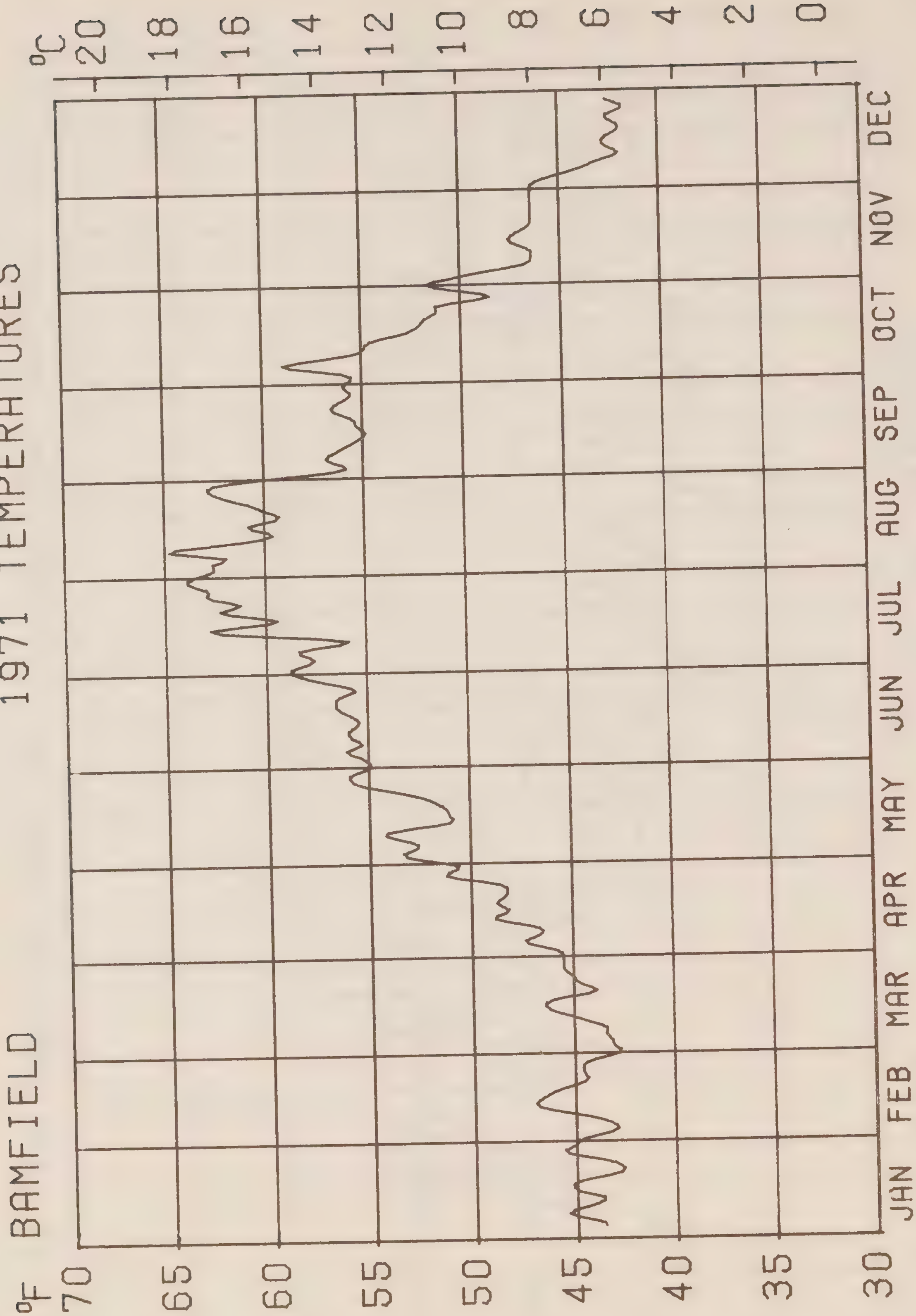
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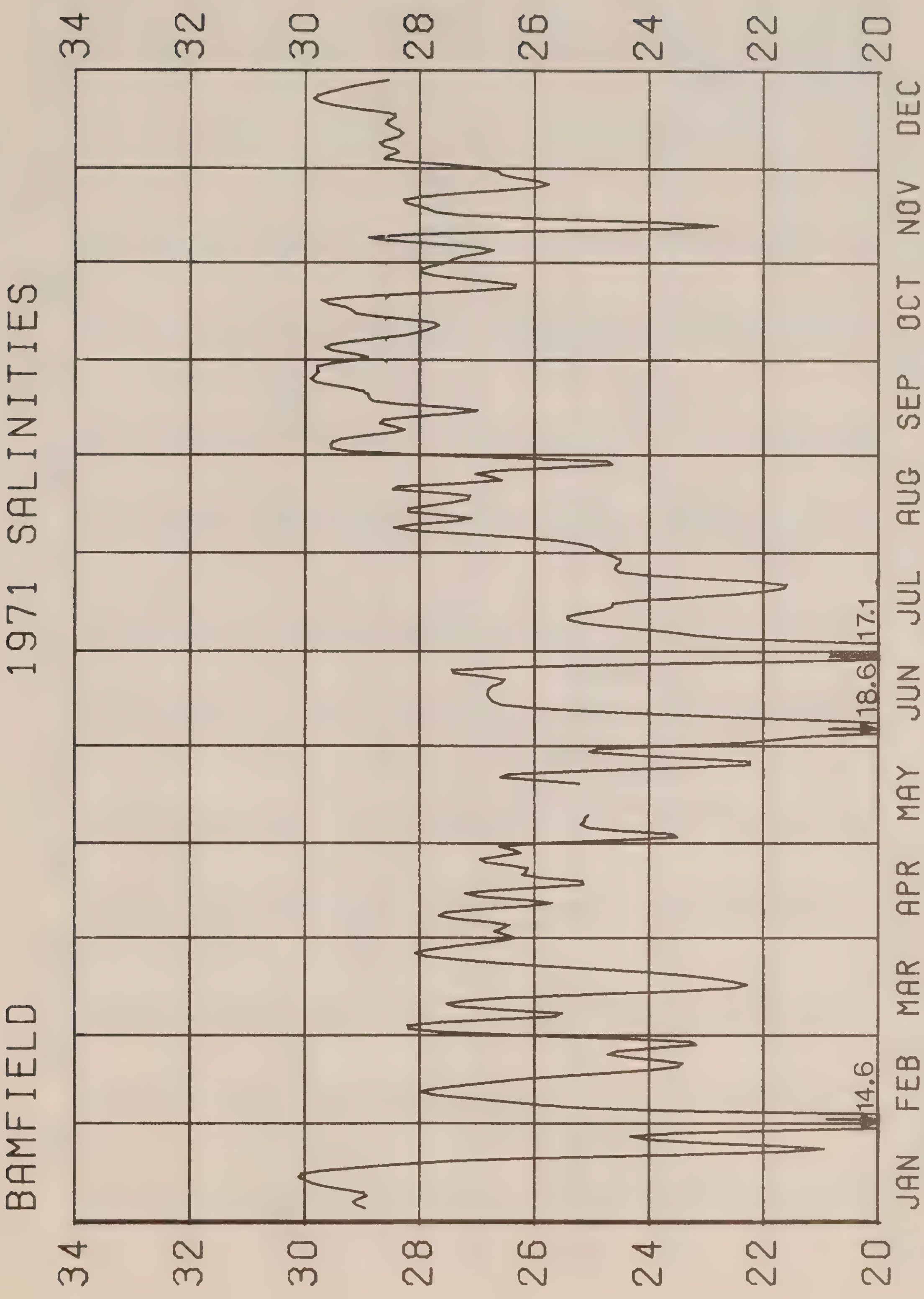
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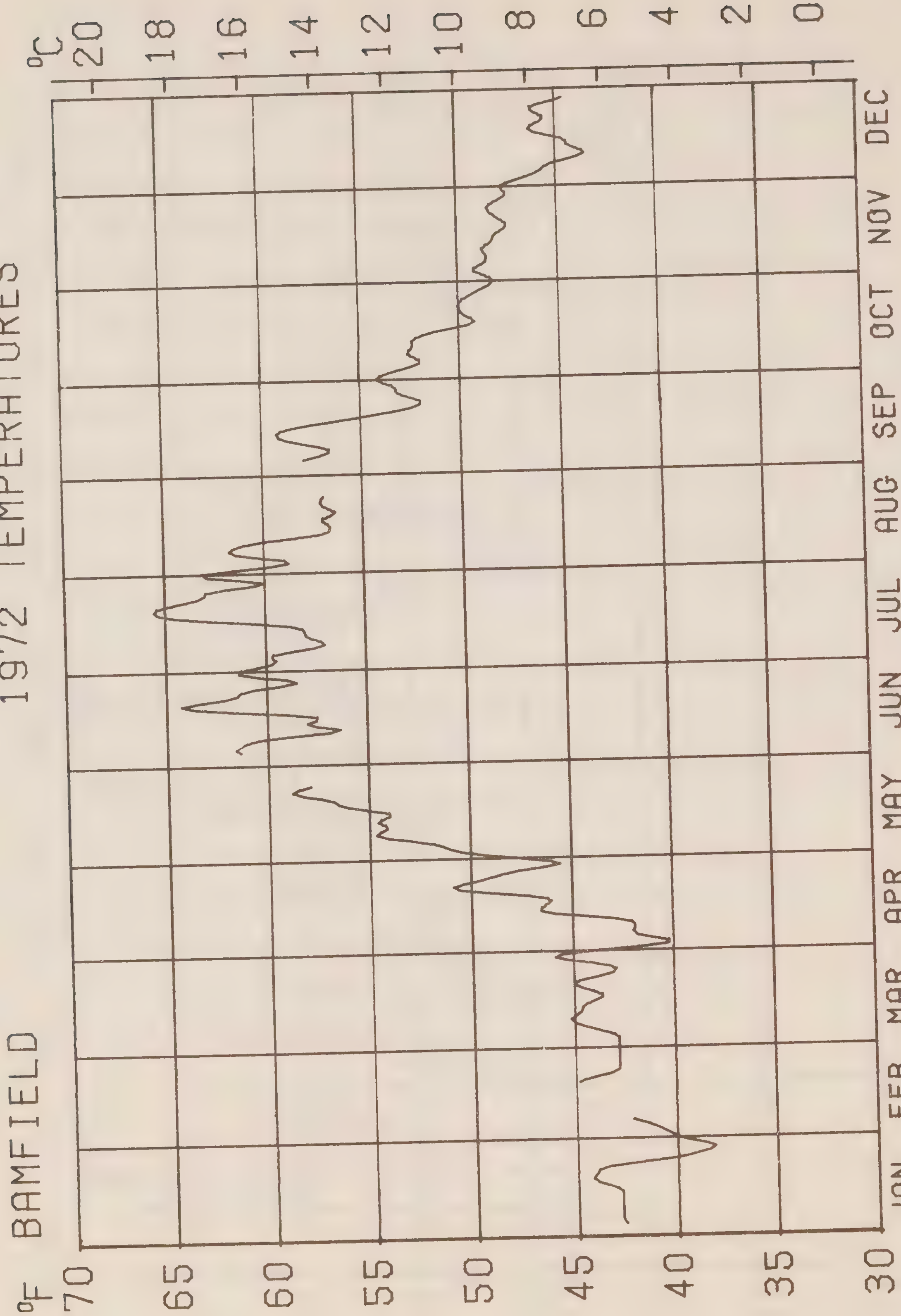
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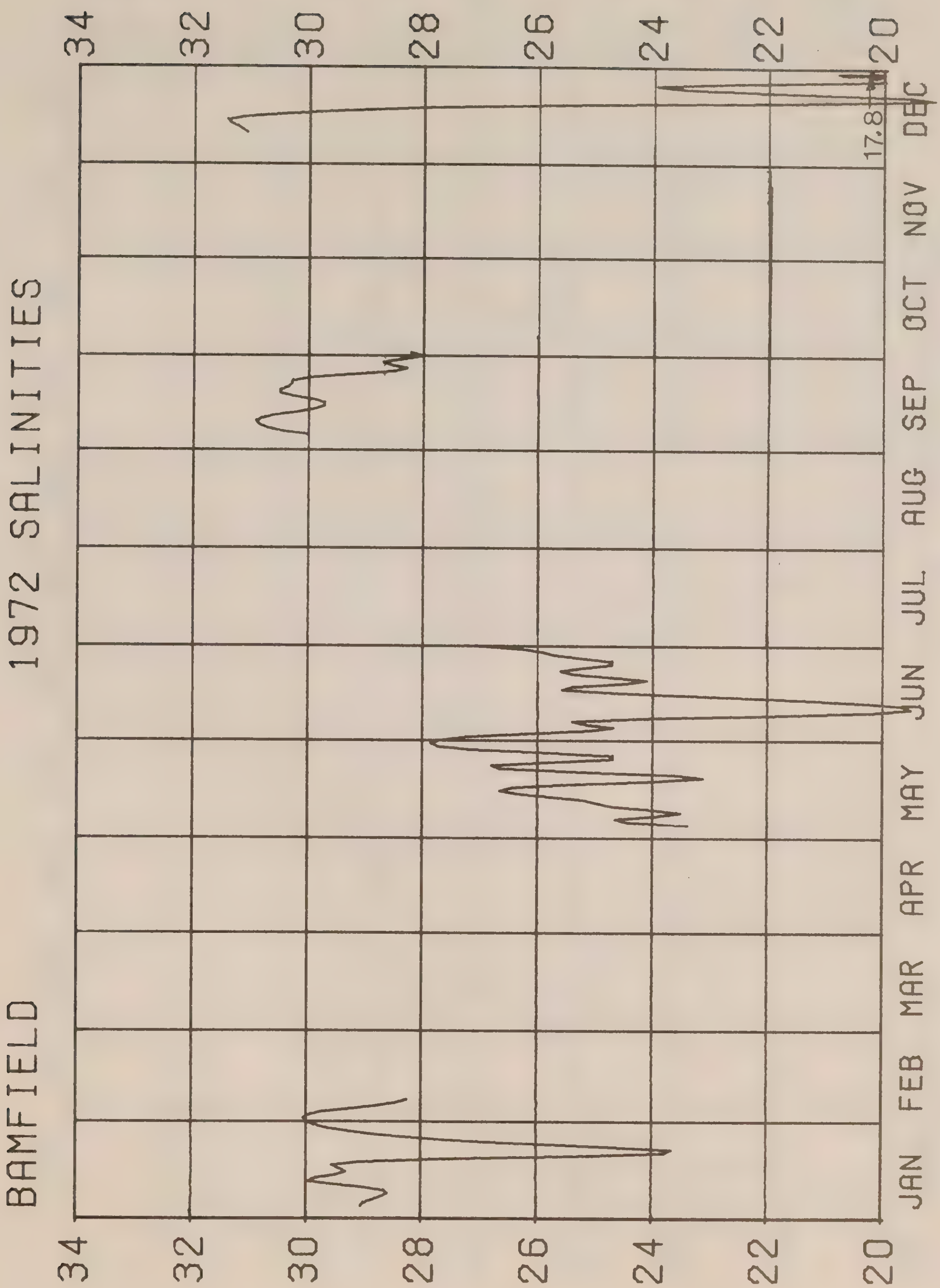
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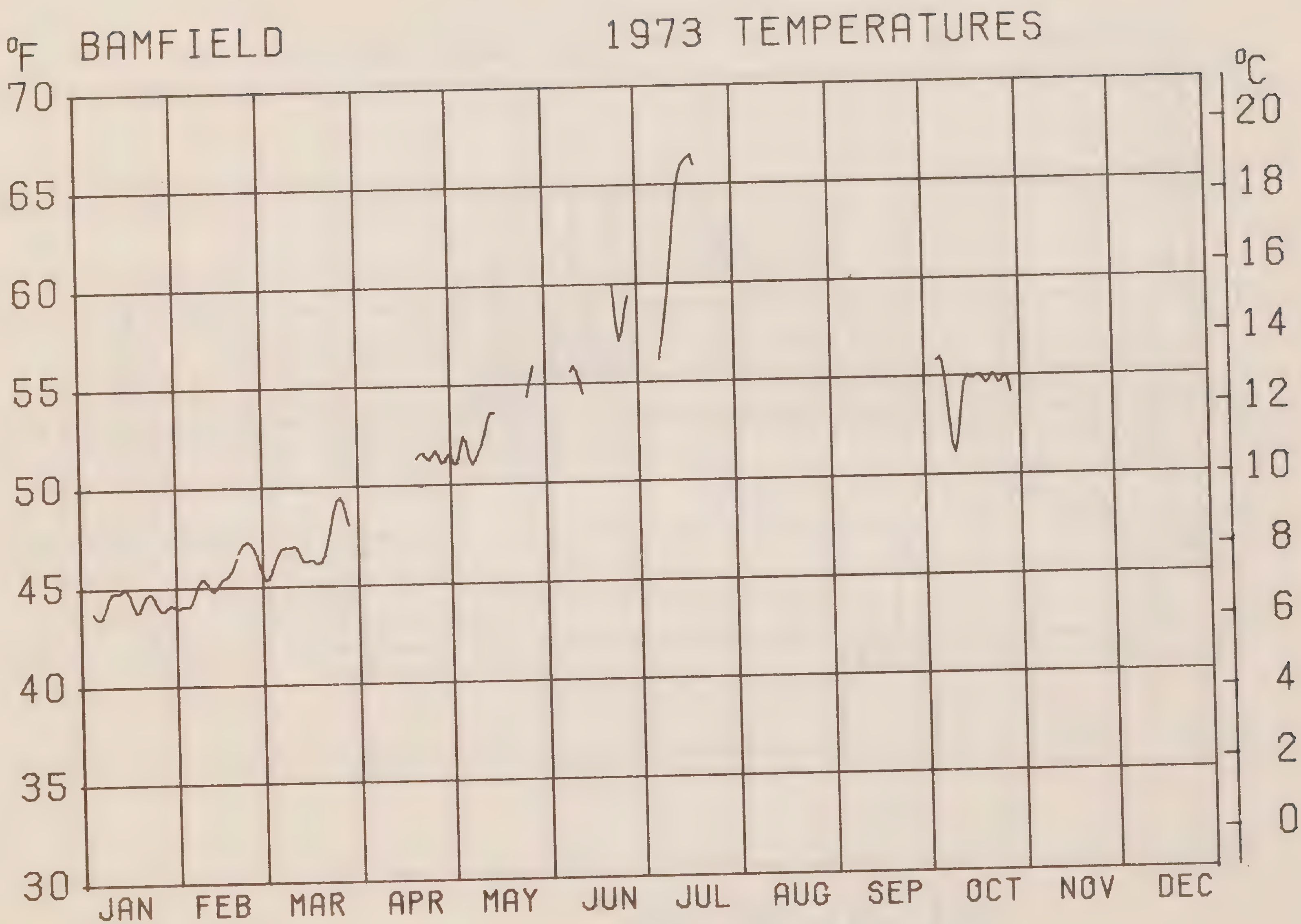

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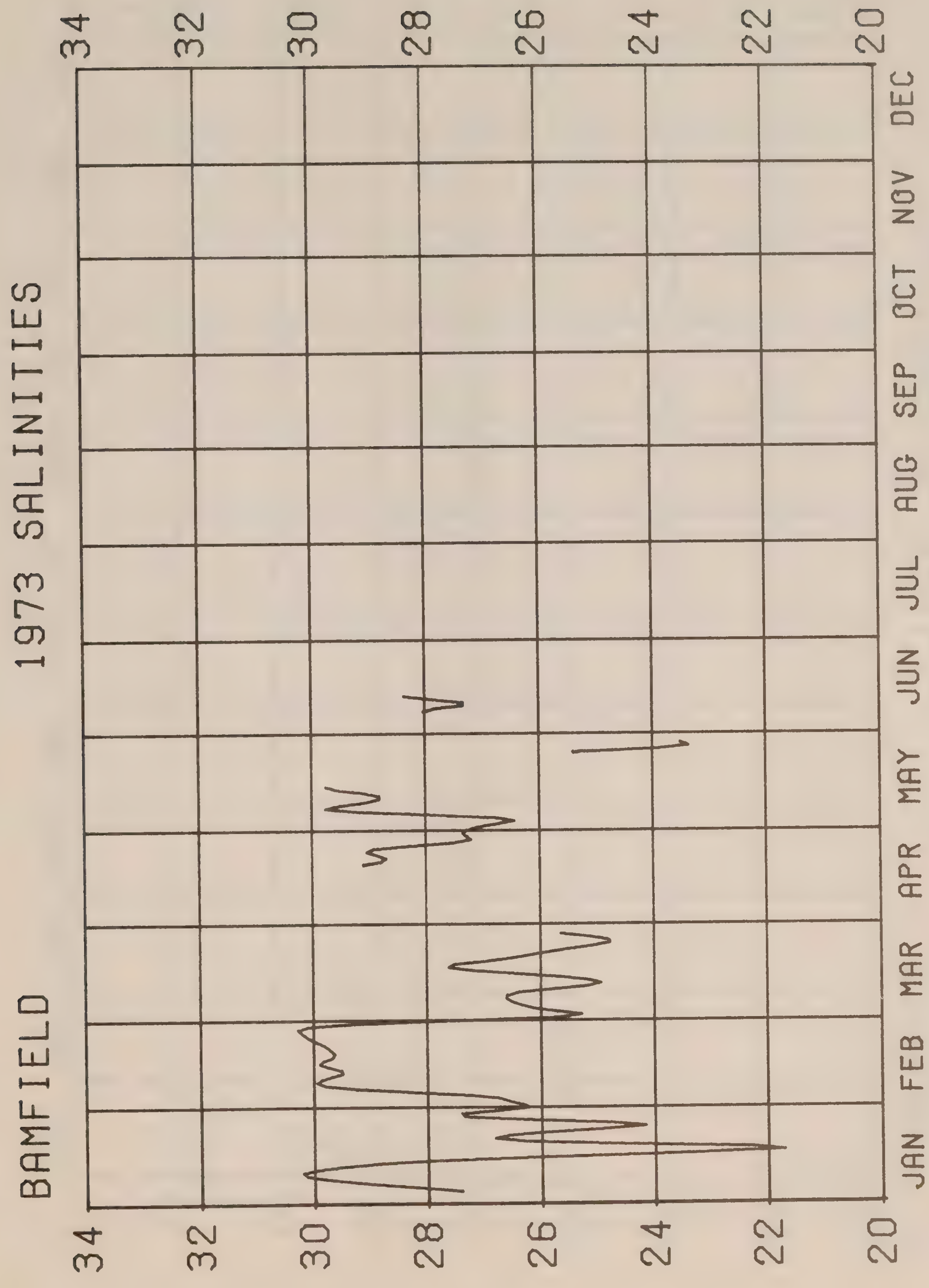
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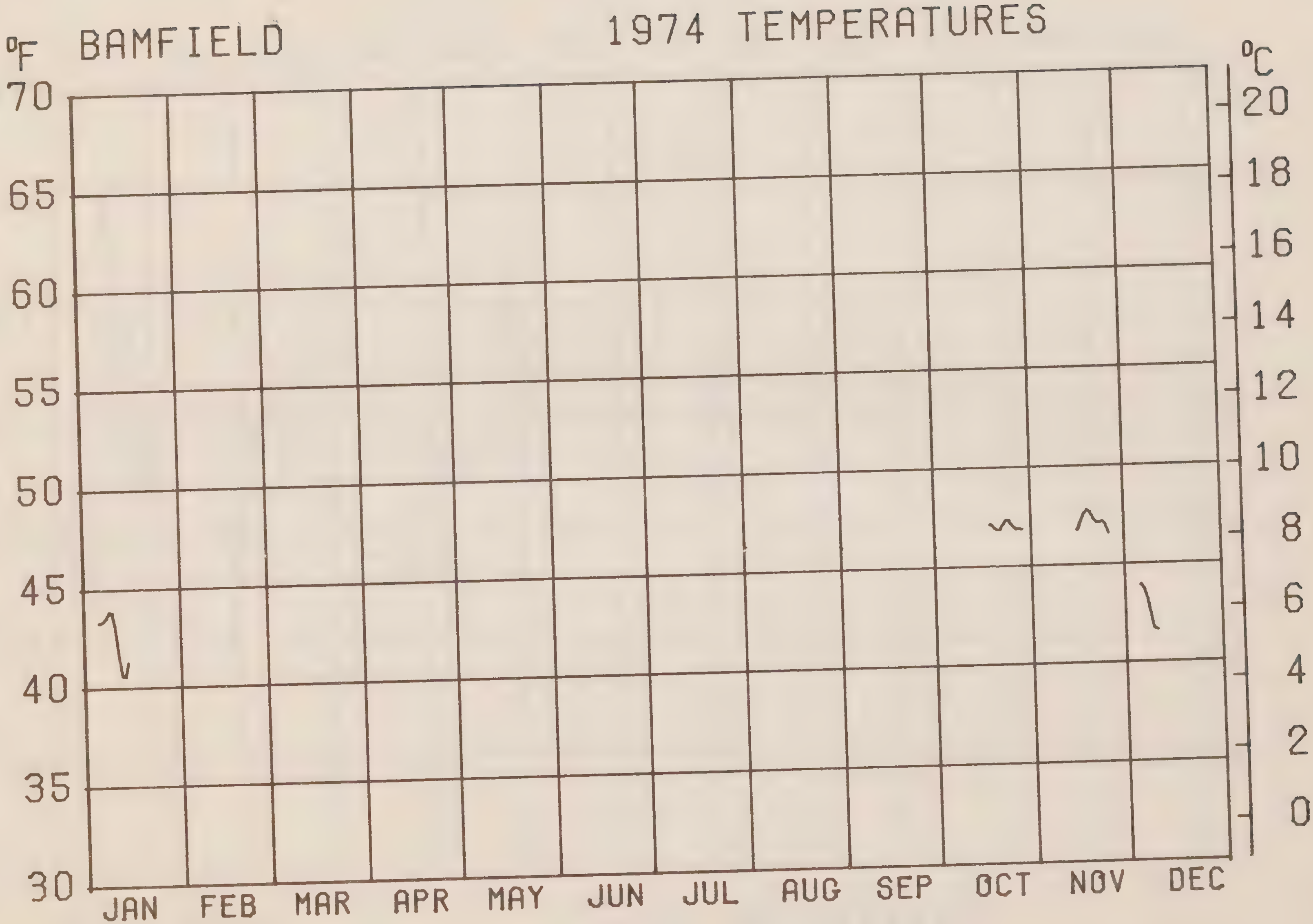
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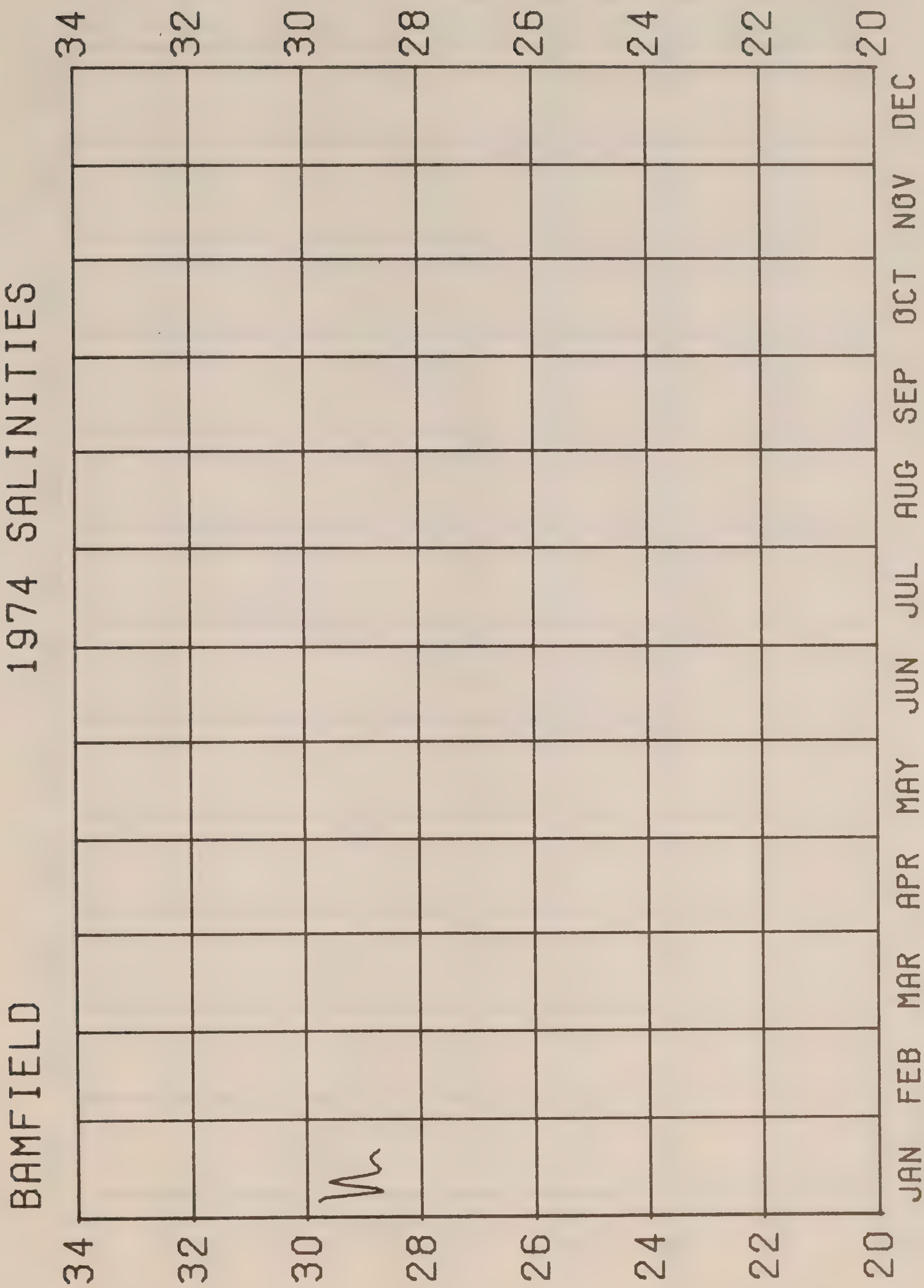
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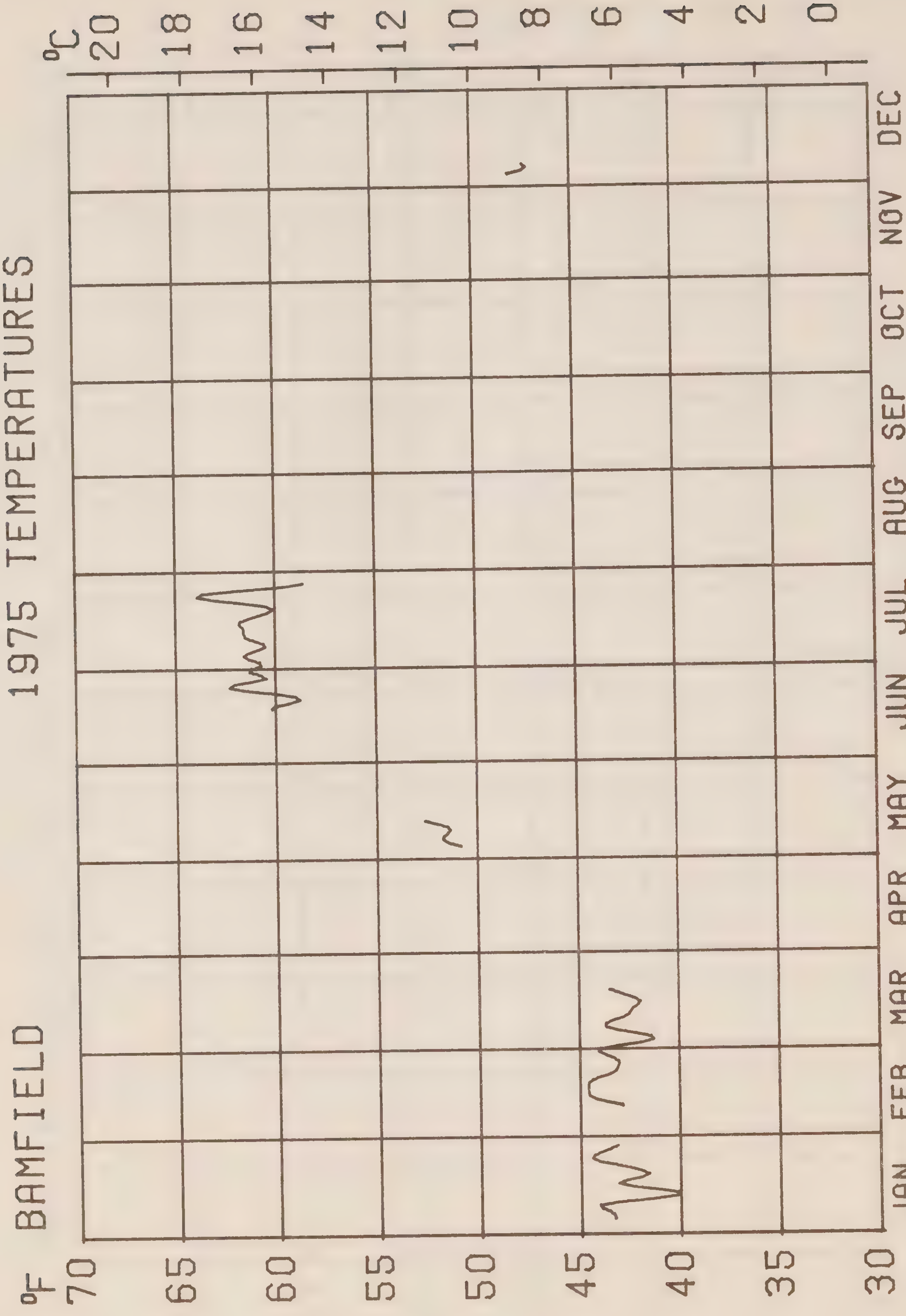

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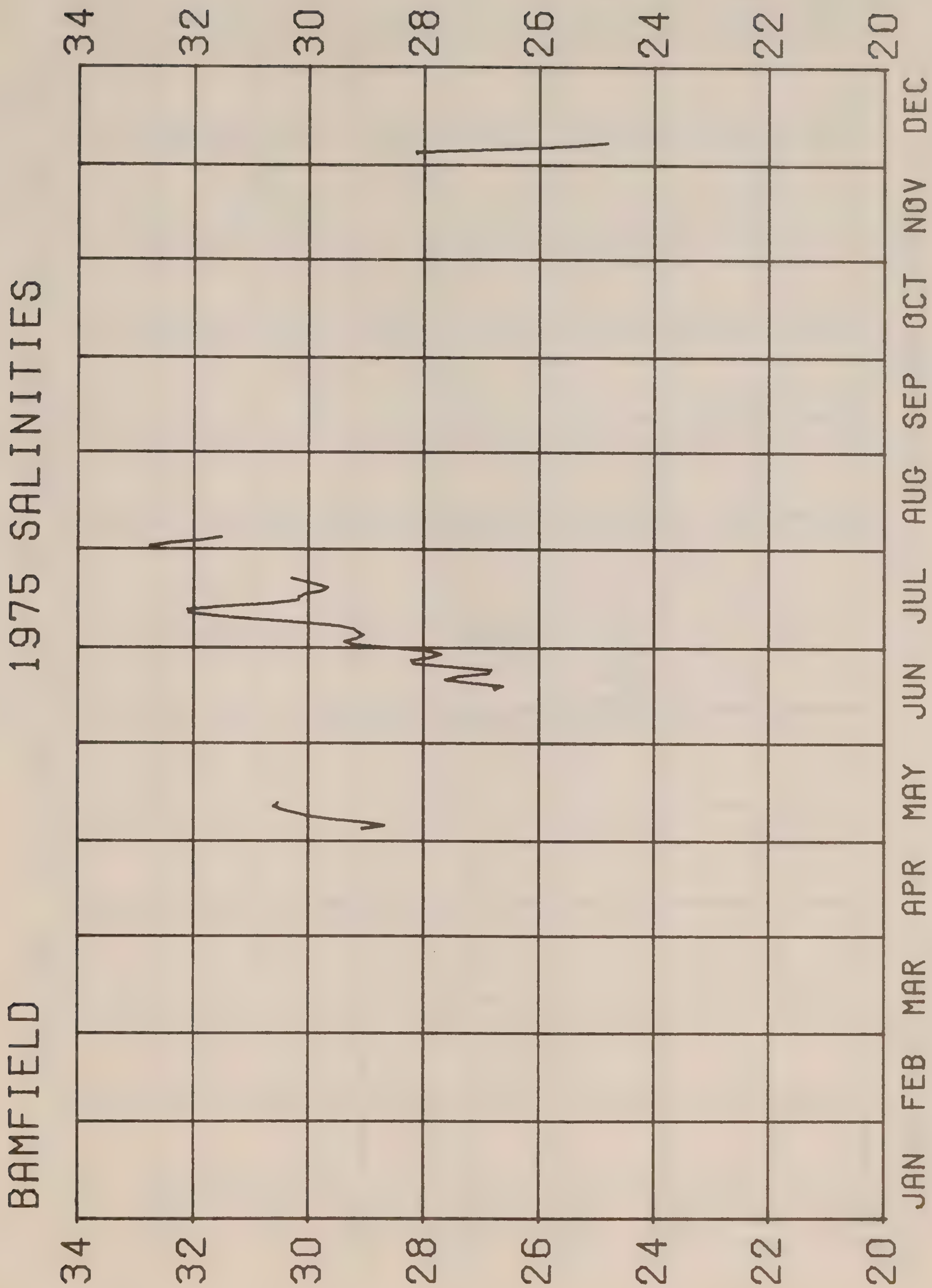
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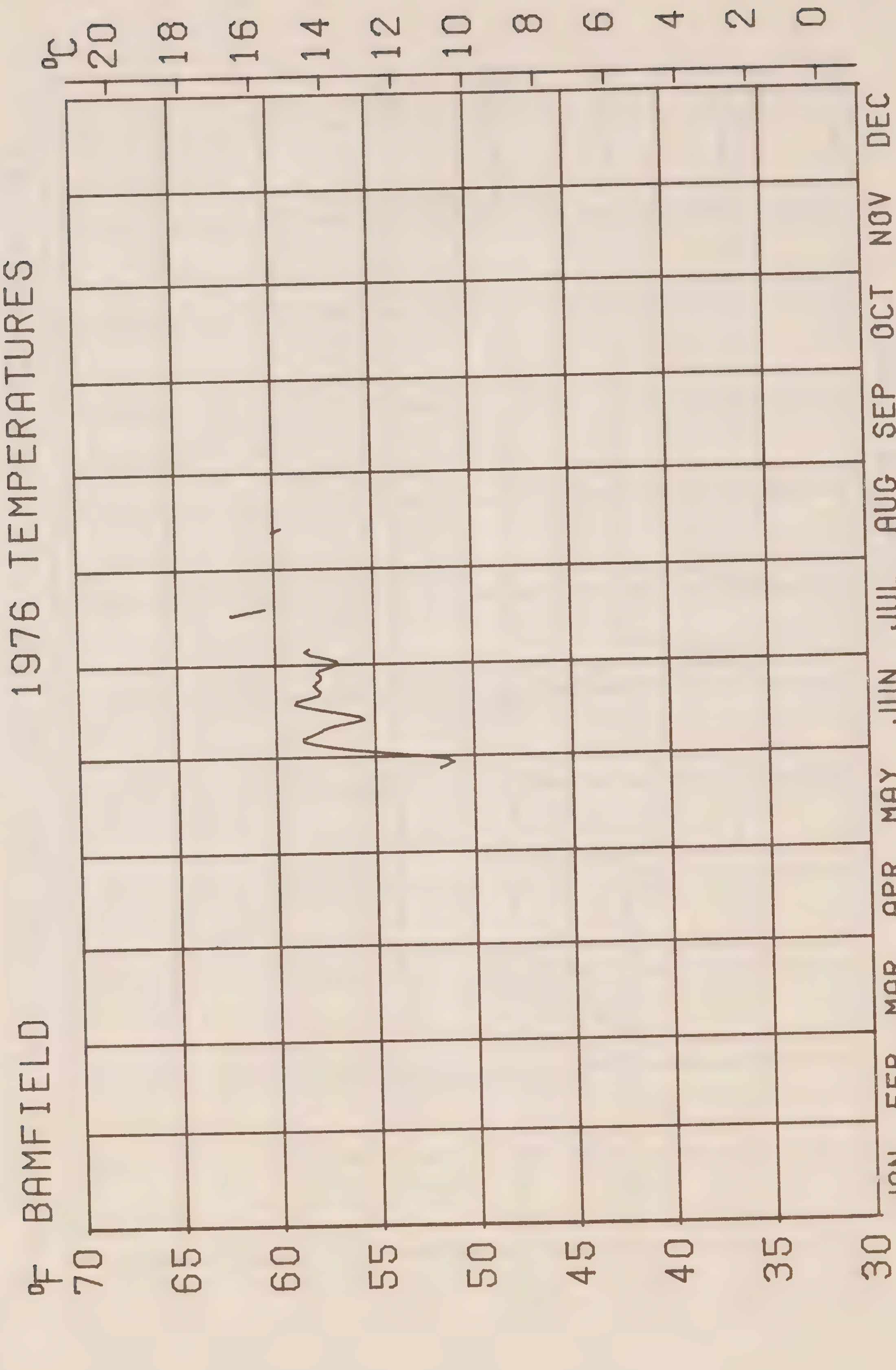
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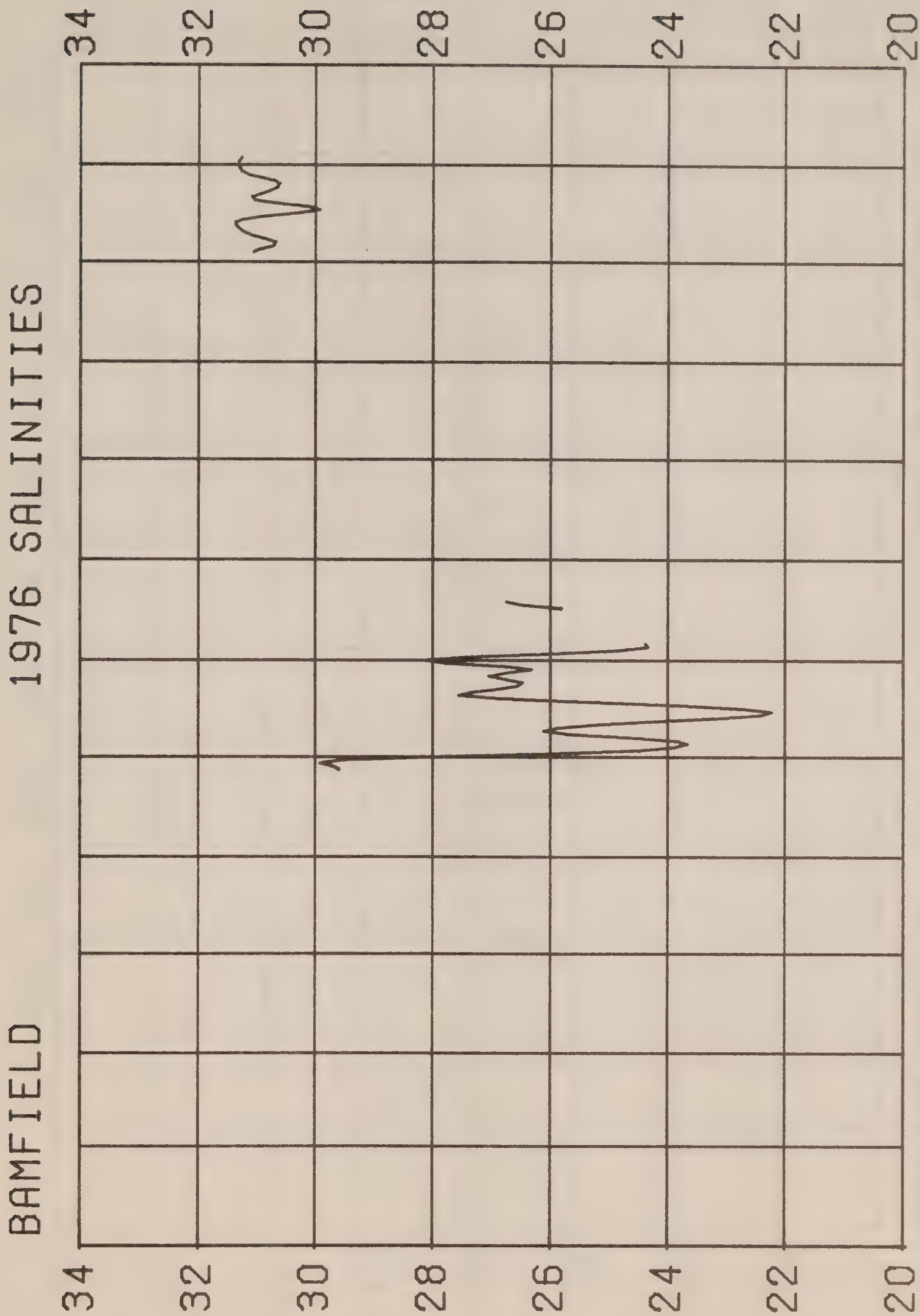
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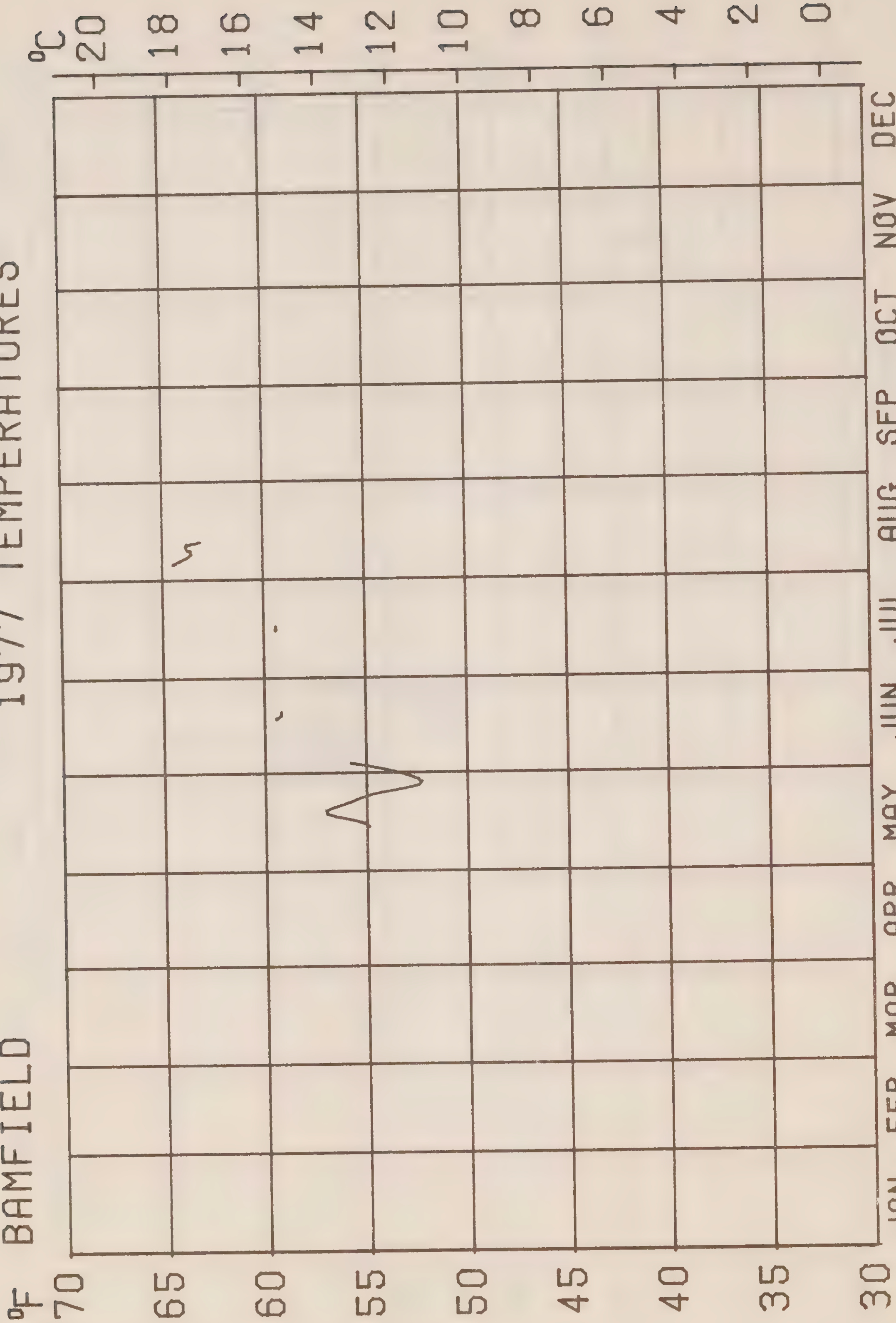
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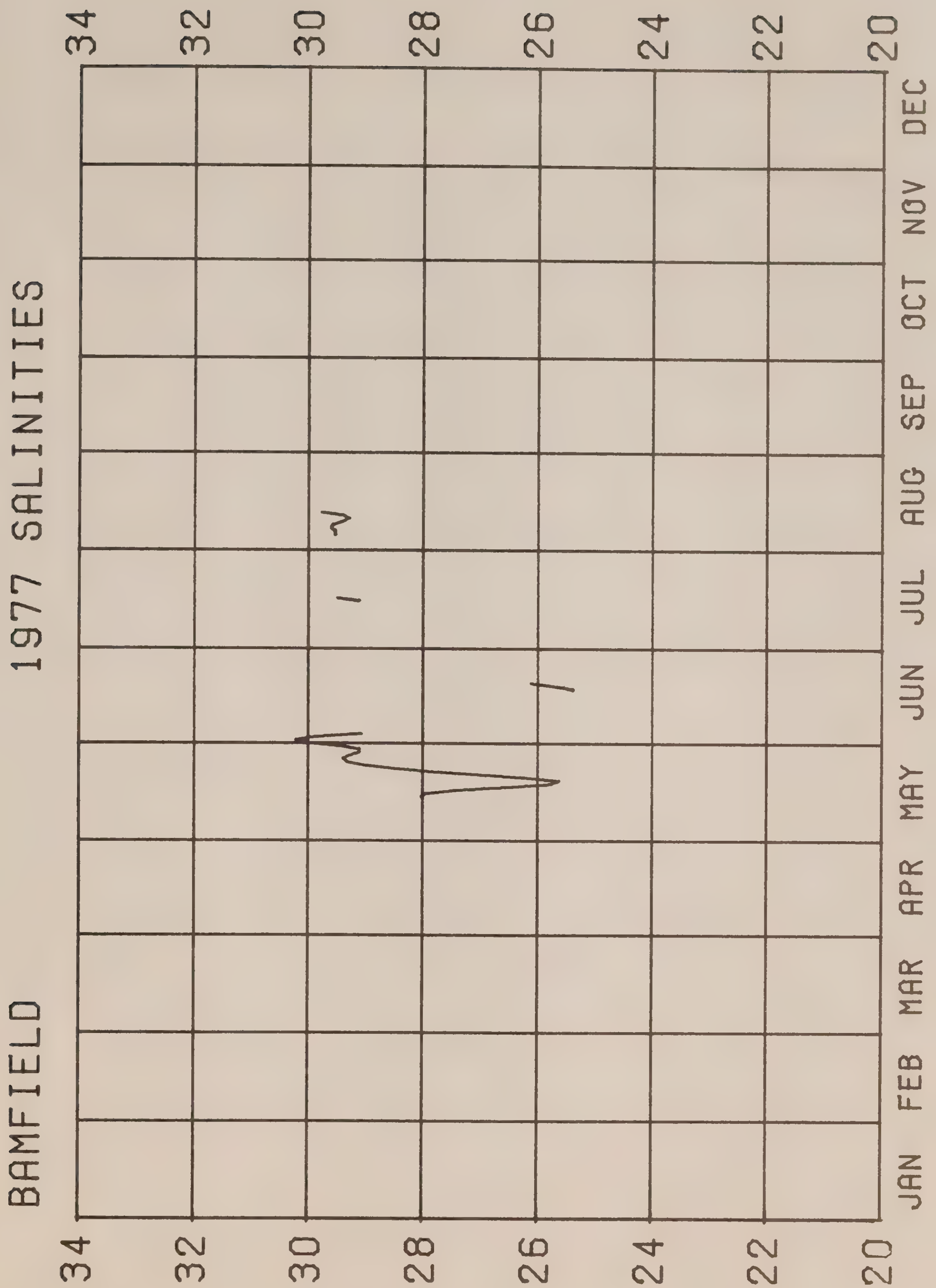
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Pacific Marine Science Report 81-7

A SIMPLE METHOD FOR MONOTONIC APPROXIMATION OF FUNCTIONS

by

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INSTITUTE OF OCEAN SCIENCES
Sidney, B.C.

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A SIMPLE METHOD FOR
MONOTONIC APPROXIMATION OF FUNCTIONS

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J.E. Papadakis

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1981

Abstract

A unique transformation of a function that is monotonic in domains of function inversions, and preserves the function's integral is derived from the theorem of parallels of Thales, and from the Archimedian method of integration. This transformation may also be called an approximation since it can be used as such. The problem arose from oceanography; some theoretical consequences and relationships to other areas are mentioned. Finally, the composed subroutines and an example from the Coastal Oceanic Dynamics Experiment (C.O.D.E.) are presented.

Table of Contents

1. Introduction

Ocean density profiles computed from *in situ* measurements of pressure, temperature, and conductivity are rarely monotonic for various reasons associated with the instruments and the medium itself. However, monotonicity of the vertical density profiles is required for static stability of the water column, and, for some instances during the automatic plotting of the isopycnals of an oceanic area. The latter concerned the author in 1978 while processing data from Knight Inlet, B.C., Canada.

In most cases, in addition to monotonicity, the intergral of the density as a function of depth must also be preserved. The reasoning is simple. This integral represents the total water mass of the water column, and in sequence, of the oceanic area.

There exists a third requirement: the numerical algorithms must introduce a minimum of noise and distortion, and be as fast as possible. An attempt to rationalize this, with the aid of decision theory is found in many works and in (Papadakis, 1973, pp. 279-287).

A consideration of the above three requirements led to the present method.

2. Construction of an integral preserving and montonic approximation to a given function.

Fig. 1 illustrates the problem. G is the given profile and A is the monotonic approximation. (For the oceanographic example, the Y axis represents density and the X axis represents depth.)

G and A coincide in the intervals where G is monotonic. When one (bounded) inversion is detected, the domains of definition and of values are defined as the closed intervals [O,L] and [O,K].

G is assumed continuous. If it is defined only at discrete points, a linear or any other monotonic interpolation scheme may be assumed. With these and the following methods of construction, the function A may be considered continuous.

Assuming continuity and closed intervals, it can be proved by a generalization of the "intermediate value theorem" (Courant, 1970, pp. 66-67; Goursat, 1959, pp. 143-146) that G and A will have, in general, at least three points in common.

An intuitive concept of "closeness" between G and A can be based on this consequence and on the property of integral invariance. Thus we can better define what we mean by saying that A approximates G.

In Figure 2 we first observe that there is always a parallel to the X axis such that: C'M' = M'E'. It will be seen later that M' is a solution point. This observation is used here because it reduces by one-half the effort

of proof: whatever is said for the upper part could be said for the lower.

At an infinitesimal distance from B' draw another parallel to the X axis. Define D such that DE = CM. The infinitesimal trapezoids C'CMM' and M'DEE' are of equal area.

Draw all the parallels to the X axis and define the corresponding points D as above. (In actuality, the term "all" depends on the numerical discriminative ability of each computer for a given length scale.) The locus of D is the function A.

In Figure 3: Area p = area q. Area r = area s.

Hence:

$$\int_0^L A dx = \int_0^L G dx$$

Uniqueness: Since the sum BC + ME is unique, the algorithm generates a unique solution. The solution A is the simplest construction of an infinite family of such solutions.

Monotonicity: "Scanning" upwards from 0 with the parallels, observe that the lengths BC and ME are both increasing. The same will happen to their sum: BC + ME = BC + MD + DE = BC + MD + CM = BD.

Generalization: Sequential or nested inversions could be treated similarily as shown in Figures 4, 5, and 6.

Degeneration: Impulses or "half" inversions could be "completed" with a vertical segment and treated as above, as shown in Figure 4.

3. Discussion

3.1 Connections with other areas

Classical filters, such as $u_n' = \frac{u_{n-1}+u_n+u_{n+1}}{3}$, do not guarantee monotonicity. For the present method, the upper limit of the "cut-off" of inversions is bound only by the rounding-off limit of each computer.

Many interesting similarities to Fourier analysis and approximation may be established if instead of "frequency" we use the term "inversion".

It is accepted that there are many states of equilibrium for an oceanic area. In the most common sense, the mean density profile of an oceanic area in equilibrium is expected to be monotonic. However, according to the known theory, the estimated mean density profile will tend to be monotonic only as the number of samples tends to infinity. Here, it seems to us that the introduction of the property of monotonicity, as a precondition, should accelerate the convergence to the ensemble mean. We expect to be closer to the mean if before the averaging we transform the given profiles as above.

We believe that the general problem belongs to the theory of variations. The condition of monotonicity and especially the definition of the domain of variation could be relaxed. But even as they stand, they reflect in physics a reordering, without mixing, of the infinitesimal water layers, backwards in time, to a supposedly initial state. The knowledge of this is useful for some energy and dynamic considerations.

If the initial condition is changed from "monotonic" to "non decreasing", and the limits of variation are left variable, then we end up with a layer of water completely mixed, predicting thus the (already known) stable isodensity layers in the ocean.

With the above in mind, the relationship of the method to the L_1 and L_∞ approximation norms (Rice, 1964) can be studied.

In those cases where the inversion is made of linear segments, the monotonic approximation is the diagonal.

Following the above generalization, for linearly segmented inversions, as shown in Figure 5, we can derive a geometrical picture of the electrical law of resistances in parallel. The slopes of the segments and of their approximation are related by:

$$\frac{1}{R} = \frac{1}{|R_1|} + \frac{1}{|R_2|} + \ldots + \frac{1}{|R_5|}$$

A similar relation in a differential form can be derived for nonlinearly segmented inversions.

The relations between the transforms of a function and its derivative are of theoretical and practical importance. They are being studied, in respect to convexity, as are the similarities to concepts related to negative resistance in electronics.

The absolute value of the area h, Figure 6, between the "diagonal" and the approximation may serve as an indicator of the nonlinearity in the segments of the inversion. If the absolute value is dropped, the value of the area is zero for linear, of course, and for symmetric inversions. For the oceanographic example, this value may be used as an indicator of the excess or deficit in water relative to the linear stratification; the algebraic sign may be used as an indicator of the water motion.

The extrema of the difference between the given function and its monotonic approximation are sometimes reasonable approximations of the roots of the function's (smoothed) derivative. Also the properties of common points, of monotonicity, and the invariance of the integral make the approximation a sort of a generalized central "inertia axis" of reference for the global changes or "breaking of symmetrics" (in the area of inversion) of the function. Since the involved computations are very simple, we could have an inexpensive method for the estimation of reasonable initial guesses for certain iterative feature extraction algorithms.

It is suggested that in some cases of integration of some "pathological" oscillatory functions, it may be more accurate to first monotonically transform the function as above, and then integrate.

Finally, it has been found that if G is a histogram then G and its monotonic transformation A have the same entropy, i.e. the transformation is entropy preserving. This is a very useful result, especially when we are dealing with the "inverse" problem in which we try to decompose a given state into simpler ones. The proof for this result is omitted here.

3.2 Two other methods used in oceanography.

Resecntly, Dr. E. Carmack of the National Waters Research Institute in Vancouver, B.C., informed us about

a) the work of Thorpe (1977) in which monotonic density profiles are constructed for the determination of a quantity related to the energy of turbulence. This method appears to be analytic and as such is restricted to simple inversions for which an integral equation could be solved.

b) The method of "vertical slices" (Wiegand and Carmack, 1980) where one generates "slices" of width ΔX and then orders them according to their height. The accuracy depends on the chosen ΔX, in addition to other numerical interpolation errors. The method presented here depends only on the interpolation errors and does not presume ordering.

4. Acknowledgements

Professor S.P. Zervos of the University of Athens, Greece, for the fundamentals. Dr. E.C. Carmack and Dr. J.F. Garrett for their fruitful discussions and suggestions. Dr. R.E. Thomson for the opportunity to apply the method during the processing of data from C.O.D.E., offshore of Vancouver Island. Professor A.D. Booth for his encouragement and for his constructive criticism of the original manuscript. Miss A. Mathias and Mrs. D. Wonnacott for typing, and Miss P. Kimber for the help in drafting.

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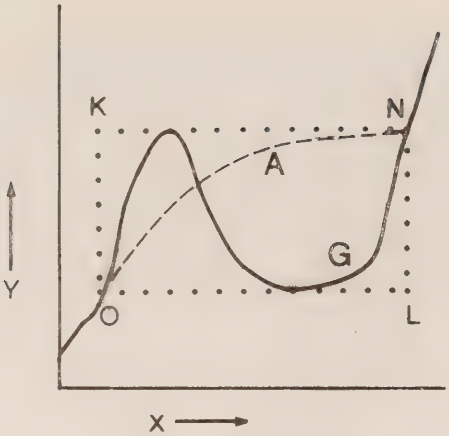


Fig. 1

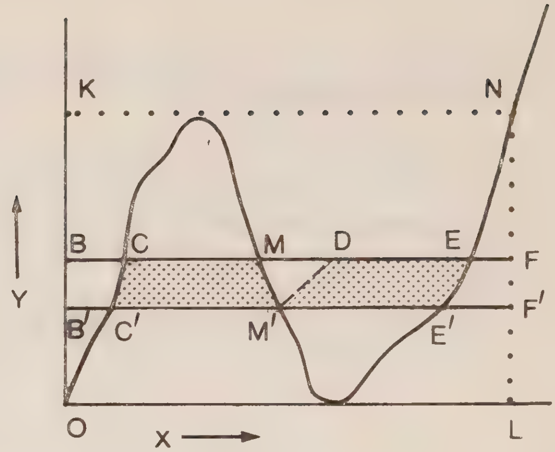


Fig. 2

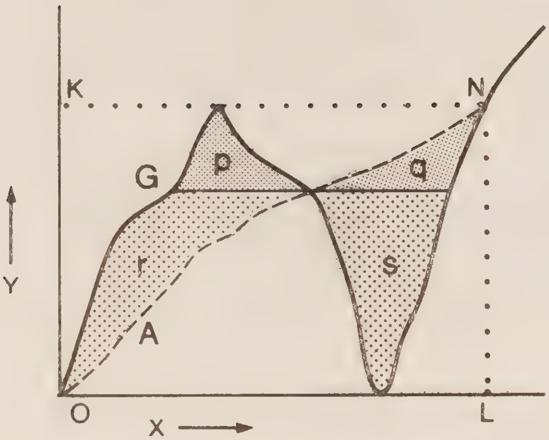


Fig. 3

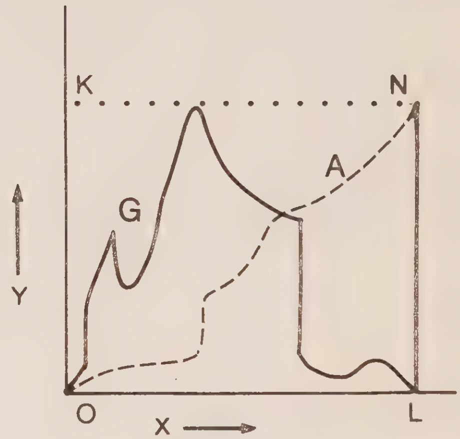


Fig. 4

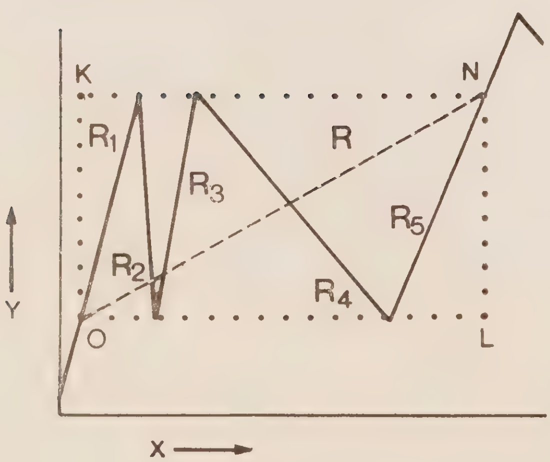


Fig. 5

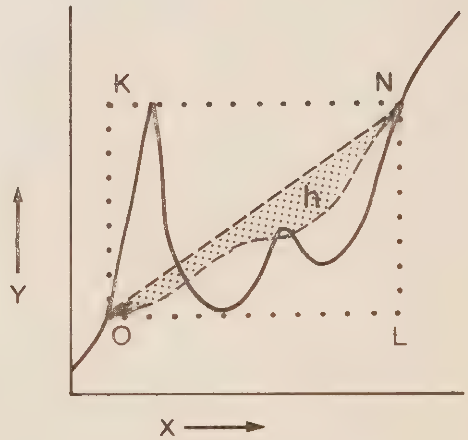
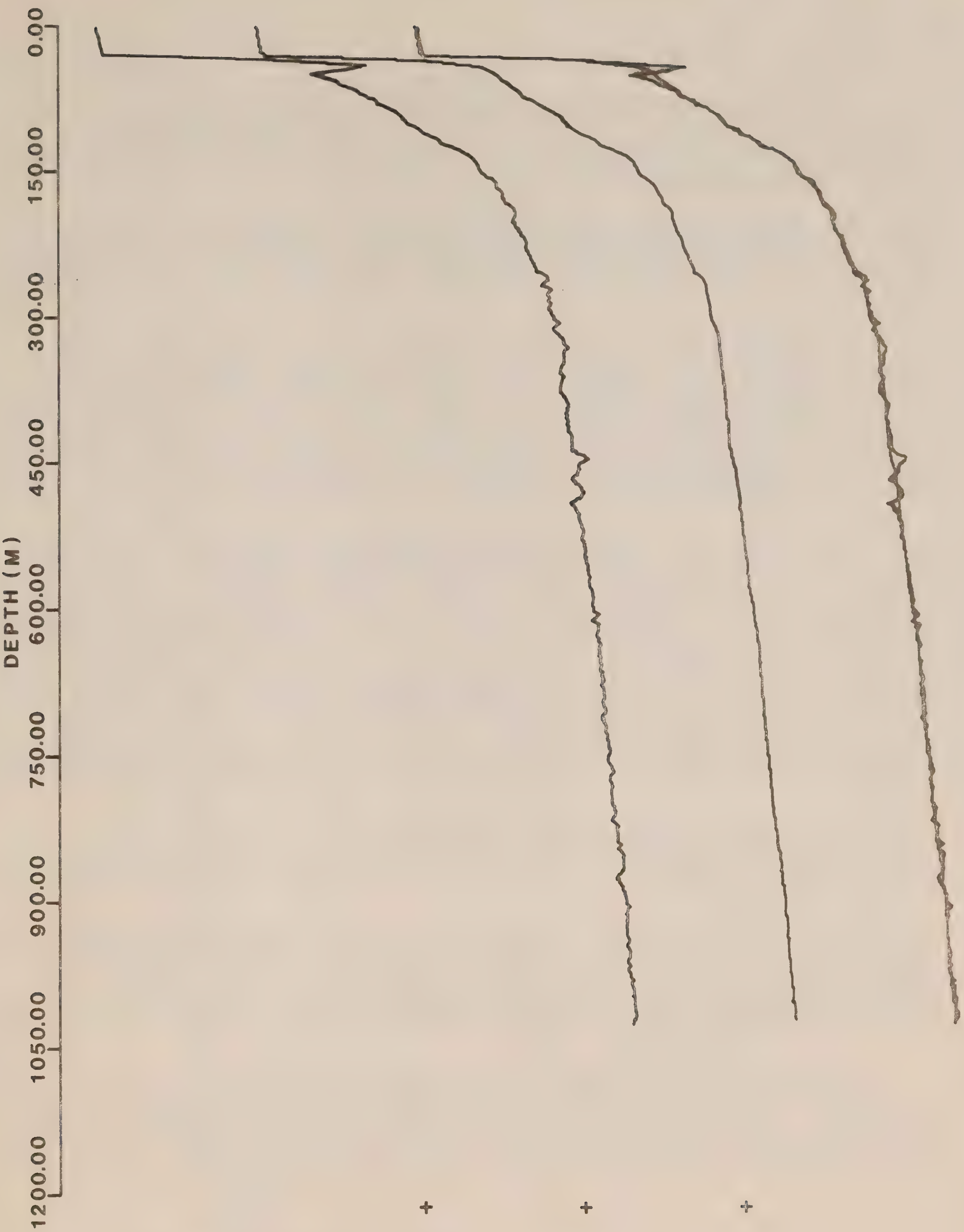


Fig. 6



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⌊____⌋ = 1.00   + = 26.0

Fig. 7

7. Appendix: An Application

The subroutine MAINIT which is presented here gives an answer to the problem: given the points (X_i, Y_i) i = 1,2,...,NDP, find for the same abscissae X_i the NDP values YP_i of their monotonically increasing and integral preserving representation.

The following subroutines contain many failsafe measures which are not necessary for all the practical situations. The structure of the subroutines is one of the many possible, and in general, the subroutines could be further optimized.

In the beginning the subroutine MAINIT calls the subroutine FIPOMA in order to set the first element of the array YP equal to Y_{min} and the last element equal to Y_{max}. Note here that the arrays X and Y which contain the original data must be declared in the main program as having dimension NDP+2. FIPOMA also will check for the possibilities of having a sequence of data with many equal ordinates, thereby constituting an inflection neighbourhood. In this case FIPOMA will reduce all these values into a proper one.

Next, MAINIT will generate NDP equally spaced values of Y and store them in the array YT. After this, subroutine MONDI is called. This subroutine realizes the method described in this work. It will generate in the array AIY all the possible abscissae for each YT_i, NIV in number, and their characterization. Each interpolated value is characterized by an integer stored in the array ICA. If ICAj = 1, the interpolated value is characterized as normal. If ICAj = 2, then the corresponding data point is located in a neighbourhood of sequenced points of equal ordinate. After subroutine FIPOMA, such inflection neighbourhood will be eliminated. Also, ICAj = 2, if the first or the last points of the array YP are in a sequence of points of equal ordinate.

The subroutine MONDI generates also the value AVY which is the average value of the NIV abscissae. This value is useful for many other applications but it is not used here.

After the above, MAINIT computes the values XT_i which corresponds to the value YT_i. The values XT_i are neither equally spaced, nor do they coincide with the original abscissae X_i. The adjustment is performed via the subroutine GIXIMY, which, using linear interpolations on the arrays XT and YT, will generate values of YP_i corresponding to X_i.

As an example of application of the subroutine MAINIT, a vertical σ_t profile was taken from cruise: C.O.D.E. :79-15, Station WC34, September 1979. The result is presented in Figure 7. On the left is the original σ_t profile, in the middle its approximation, and on the right both have been superimposed.

```
REDISUM*JEPSUB(1).MAINIT
      C
            SUBROUTINE MAINIT(NDP,X,Y,YP)
      C *DRIVER SUBROUTINE FOR MONOTONIC AND INTEGRAL PRESERVING
      C *TRANSFORMATION  *
      C  ***  GIVEN THE ARRAYS X AND Y THE ARRAY YP IS PRODUCED.
      C  ***  J.E. PAPADAKIS. OAS/OFFSHORE OCEANOGRAPHY. JULY 1980.  *
            DIMENSION X(2),Y(2),YP(2)
            DIMENSION XT(300),YT(300),XP(300),AIY(300),ICA(300)
      C
            CALL FIPOMA(NDP,X,Y,NP,XP,YP)
      C
            YAR = YP(1)
            SPA = YP(NP) - YAR
            STP = SPA/(NDP-1)
            DO 3 I=1,NDP
            VY = YAR + (I-1)*STP
            YT(I) = VY
            CALL MONDI(1,NP,YP,XP,VY,AVY,NIV,AIY,ICA)
            VX = AIY(1)
      C
            IF(NIV .NE. 1) GO TO 11
            IF(ICA(1) .EQ. 2) VX = 0.0
            GO TO 2
         11 CONTINUE
      C
            IND = -1
            IF(ICA(1) .NE. 2) GO TO 1
            VX = 0.0
            IND = 1
          1 CONTINUE
            DO 2 J=2,NIV
            IF(ICA(J) .EQ. 2) GO TO 2
            VX = VX + IND*AIY(J)
            IND = -IND
          2 CONTINUE
            XT(I) = VX
          3 CONTINUE
            XT(1) = XP(1)
            XT(NDP) = XP(NP)
      C
            WRITE(6,*) NP
            NDM = NDP - 1
            DO 4 I=2,NDM
            XX = X(I)
            CALL GIXIMY(1,NDP,XT,YT,XX,VY)
            YP(I) = VY
          4 CONTINUE
            YP(NDP) = YP(NP)
            RETURN
            END
```

```
REDISUM*JEPSUB(1).FIPOMA
      C
            SUBROUTINE FIPOMA(NDP,X,Y,NP,XP,YP)
            DIMENSION X(2),Y(2),XP(2),YP(2)
            LOGICAL FL
      C
      C  **  < FIRST PROCESSING OF M.A. >
      C  **  1) TO SET THE FIRST ELEMENT = YMIN AND THE LAST = YMAX
      C  **  2) TO REDUCE THE MANY,EQ.,AND IN SEQ. INFLECTION  .
      C          POINTS TO ONE.
      C  **  ARRAYS X AND Y MUST HAVE DIMENSION ≥ THAN NDP+2 .  **
      C
            AA = 1.0E-9
            LEQ = 0
            XZ = X(1)
            YZ = Y(1)
            XP(1) = XZ
            YP(1) = YZ
            NI = 1
            FL = .FALSE.
            YMI = YZ
            YMA = YZ
            PX = XZ
            PY = YZ
      C
            DO 11 I=2,NDP
            XX = X(I)
            YY = Y(I)
            IF(YY .LT. YMI) YMI = YY
            IF(YY .GT. YMA) YMA = YY
         11 CONTINUE
      C
            NP = NDP
            IF(YZ .LE. YMI) GO TO 5
            PY = YMI
            NP = NP + 1
            Y(1) = YMI
            DO 4 I=2,NDP
            XIZ = X(I)
            YIZ = Y(I)
            X(I) = XZ
            Y(I) = YZ
            XZ = XIZ
            YZ = YIZ
          4 CONTINUE
            X(NP) = XZ
            Y(NP) = YZ
      C
          5 IF(Y(NP) .GE. YMA) GO TO 6
            NP = NP + 1
            X(NP) = X(NP-1)
            Y(NP) = YMA
          6 CONTINUE
      C
      C
            XP(1) = X(1)
            YP(1) = YMI
```

```
C
      DO 3  I=2,NP
      XX = X(I)
      YY = Y(I)
      TMC = YY - PY
      SED = ABS(TMC)
C
      CED = SED
      IF(FL) BAD = ABS(YLA-YY)
      IF(I .EQ. 2) BAD = SED
      IF(FL) CED = BAD
C
C
      IF(CED .GT. AA) GO TO 1
      IF(FL) GO TO 2
      FL = .TRUE.
      LA = I - 1
      YLA = Y(LA)
      GO TO 2
C
    1 IF( .NOT. FL) GO TO 2
      FL = .FALSE.
      NNI = 1
      IF(LA .GT. 1) NNI = LA-1
      GD = (PY - Y(NNI))*(PY - YY)
      IF(GD .GE. 0.0) GO TO 2
C
      XE = (X(LA) + PX)/2.0
      CMP = PY - Y(NNI)
      FID = ABS(CMP)
      NI = LA - LEQ
      LEQ = LEQ + I - LA
      IF(FID .NE. SED) GO TO 32
      LEQ = LEQ - 1
      XP(NI) = XE
      YP(NI) = PY
      GO TO 2
   32 CONTINUE
      IF(FID .GT. SED) GO TO 33
      LEQ = LEQ - 2
      XP(NI) = XE
      YP(NI) = PY
      NI = NI + 1
      YP(NI) = PY + CMP
      XP(NI) = PX + FID*(XX-PX)/SED
      GO TO 2
   33 CONTINUE
      LEQ = LEQ - 2
      YP(NI) = PY - TMC
      XP(NI) = X(LA) - SED*(X(LA)-X(NNI))/FID
      NI = NI + 1
      XP(NI) = XE
      YP(NI) = PY
C
    2 NI = NI + 1
      XP(NI) = XX
      YP(NI) = YY
```

```
      PX = XX
      PY = YY
    3 CONTINUE
      NP = NI
      RETURN
      END
```

```
OHNGARRETT*JEPSUB(1).MONDI
C
      SUBROUTINE MONDI(IA,IT,X,Y,VX,AVY,NIV,AIY,ICA)
C
C    ** < MONDI >   MONOTONIC OR NON DECREASING INTERPOLATION. **
C    ** OFFSHORE OCEANOGRAPHY. J.E. PAPADAKIS. APRIL 1980. ***
C
C  AIY  HOLDS THE FOUND NIV INTERPOLATED VALUES OF Y FOR THE
C        GIVEN VX.
C  AVY  GIVES THE (AVERAGED) INTERPOLATED VALUE OF Y.
C    ** ICA HOLDS THE CHARACTERIZATION OF EACH INTERPOLATED POINT.
C    ** IF ICA(I) = 1 NORMAL. IF ICA(I) = 2 EXTREMUM, OR, BETWEEN
C    ** EQUAL, AND IN SEQUENCE; ALSO 2 IF Y(IA) OR Y(IT) IN A
C    ** SEQUENCE OF EQUAL ORDINATES.
C    ** AFTER JEPSUB.FIPOMA THERE IS NOT A SEQ. OF EQ. INFL. POINTS
C
C
      DIMENSION X(2),Y(2),AIY(2),ICA(2)
C
      AA = 1.0E-8
C
      PX = X(IA)
      NIV = 0
      SUM = 0.0
      IF(VX .GE. PX) GO TO 61
      AVY = Y(IA)
      GO TO 5
   61 IF(VX .LE. X(IT)) GO TO 62
      AVY = Y(IT)
      GO TO 5
   62 CONTINUE
C
      DO 2 , I=IA+1,IT
C
      XX = X(I)
      DP = VX - PX
      DC = VX - XX
      ADP = ABS(DP)
      ADC = ABS(DC)
      ICH = 1
C
      IF(ADP .GT. AA) GO TO 52
      VIN = Y(I-1)
      IF(I .NE. IA+1) GO TO 72
      IF(ADC .LE. AA) ICH = 2
      GO TO 55
   72 IF(I .NE. IT) GO TO 73
      IF(ADC .LE. AA) ICH = 2
      GO TO 55
   73 PP = X(I-2)
      DA = VX - PP
      APP = ABS(DA)
      GD = DA*DC
      IF((APP .GT. AA).AND.(ADC .GT. AA).AND.(GD .GT. 0.0)) ICH =
      IF((APP .LE. AA).AND.(ADC .LE. AA)) ICH = 2
      GO TO 55
   52 IF(I .NE. IT) GO TO 53
```

```
      IF(ADC .GT. AA) GO TO 53
      VIN = Y(I)
      ICH = 2
      GO TO 55
 53   G = DP*DC
      IF((G .GE. 0.0) .OR. (ADC .LE. AA)) GO TO 1
      PY = Y(I-1)
      YY = Y(I)
      VIN = YY + ((XX - VX)*(PY - YY))/(XX - PX)
 55   NIV = NIV + 1
      AIY(NIV) = VIN
      ICA(NIV) = ICH
C
      IF((I .NE. IT).OR.(ADC .GT. AA)) GO TO 1
      NIV = NIV + 1
      AIY(NIV) = Y(IT)
      ICA(NIV) = 2
C
C
    1 PX = XX
    2 CONTINUE

      DO 3 J=1,NIV
      SUM = SUM + AIY(J)
  3   CONTINUE
      AVY = SUM/NIV
  5   CONTINUE
C
      RETURN
      END
C
```

IN

```
REDISUM*JEPSUB(1).GIXIMY
C
          SUBROUTINE GIXIMY(IA,IT,X,Y,VX,VY)
C   **     < GIVEN X INTERPOLATE MONOTONICALLY Y . >
          DIMENSION X(2),Y(2)
C
          AA = 1.0E-20
C
          PX = X(IA)
          IF(VX .GE. PX) GO TO 11
          VY = Y(IA)
          GO TO 5
   11     IF(VX .LE. X(IT)) GO TO 12
          VY = Y(IT)
          GO TO 5
   12     CONTINUE
C
          DO 2 , I=IA+1,IT
C
          XX = X(I)
          DP = VX - PX
          DC = VX - XX
          ADP = ABS(DP)
          ADC = ABS(DC)
C
          IF(ADP .GT. AA) GO TO 52
          VY = Y(I-1)
          GO TO 5
   52     IF(I .NE. IT) GO TO 53
          IF(ADC .GT. AA) GO TO 53
          VY = Y(I)
          GO TO 5
   53     G = DP*DC
          IF((G .GE. 0.0) .OR. (ADC .LE. AA)) GO TO 1
          PY = Y(I-1)
          YY = Y(I)
          VIN = YY + ((XX - VX)*(PY - YY))/(XX - PX)
          VY = VIN
          GO TO 5
C
    1     PX = XX
    2     CONTINUE
C
    5     CONTINUE
C
          RETURN
          END

@FIN
```